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GEODESY

Determinations of Latitude, Gravity, and the Magnetic Elements

AT

STATIONS IN THE HAWAIIAN ISLANDS

INCLUDING

A Result for the Mean Density of the Earth

1891, 1892

By E. D. PRESTON, Assistant

Submitted for publication June 30, 1894

APPENDIX No. 12—REPORT FOR 1893

98

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1891, 1892.

A report by E. D. PRESTON, Assistant.

Submitted for publication June 30, 1894.

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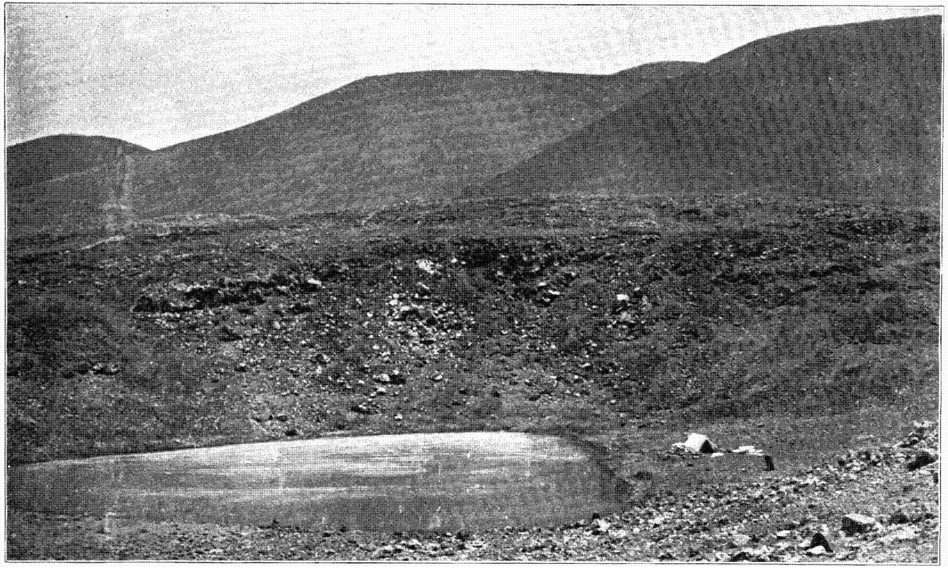


GRAVITY, LATITUDE, AND MAGNETIC STATION AT WAIAU, LOOKING NORTHEAST.

APPENDIX No. 12—1893.

DETERMINATIONS OF LATITUDE, GRAVITY, AND THE MAGNETIC ELEMENTS AT STATIONS IN THE HAWAIIAN ISLANDS, INCLUDING A RESULT FOR THE MEAN DENSITY OF THE EARTH. 1891, 1892.

A report by E. D. PRESTON, Assistant.
Submitted for publication June 30, 1894.

While engaged in astronomical observations in the Hawaiian Islands in 1891–92, in cooperation with the work of the International Geodetic Association, occasion was taken to make a continuous study for one year of the force of gravity at Waikiki.

After the work had been completed at this place an expedition was undertaken to the summit of Mauna Kea, an extinct crater, having an elevation of 13 825 feet. The object of this trip was the determination of the force of gravity at the base and summit, from which the density of the mountain and the mean density of the earth might be deduced. Availing ourselves of the occupation of this unique station, magnetic, latitude, and hypsometrical observations were carried on, besides making a trigonometric and topographic survey of the great plateau at an elevation of about 12 500 feet. When this was done, some magnetic observations were made at other points of the group, notably at Napoopoo, Kealakeakua Bay, on the lee side of Hawaii, where Captain Cook made similar observations in 1779, and at Lahaina, Maui, where De Freycinet had an observatory in 1819. For an account of other work done in the Hawaiian Islands in 1891–92 the reader is referred to Appendix No. 12, Coast and Geodetic Survey Report, 1891 (Transit of Mercury); Appendix No. 13, Coast and Geodetic Survey Report, 1891 (Preliminary note on the occupation of stations in the Hawaiian Islands); Appendix No. 2, Report for 1892 (On the variation of latitude at Waikiki, near Honolulu, from observations made in connection with the International Geodetic Association), and Bulletin No. 28, on the Constant of Aberration.

The following report has to deal with—

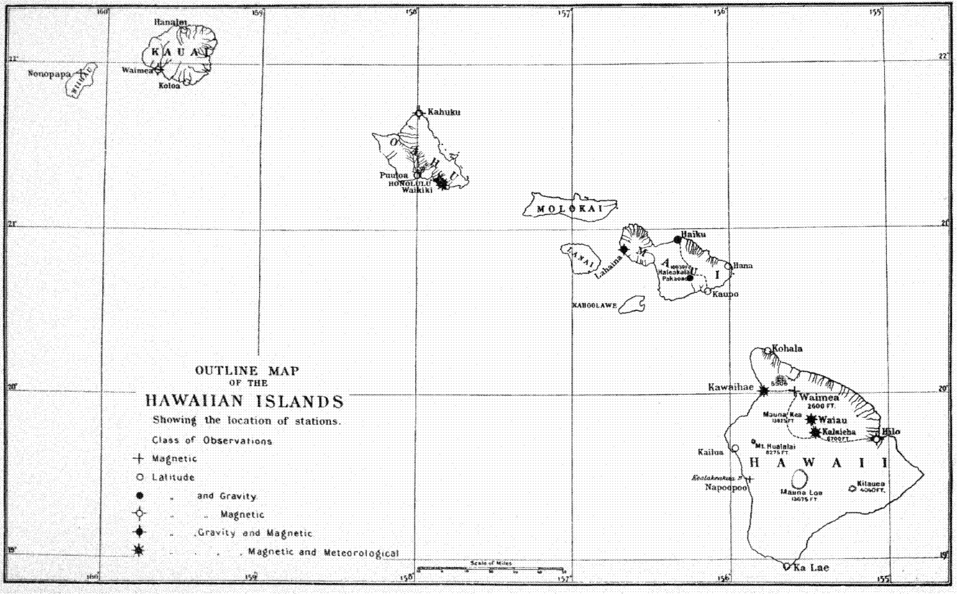
I. Gravity observations at Waikiki.
II. Gravity observations at Honolulu, Kawaihae, Kalaieha, and Waiau (summit of Mauna Kea).
III. Latitude observations at Kawaihae, Kalaieha, Waiau, and Lahaina.
IV. Magnetic observations at Kahuku, Waikiki, and Honolulu, on Oahu; at Kawaihae, Waimea, Kalaieha, Waiau, Hilo, and Napoopoo, on Hawaii; at Lahaina, on Maui; at Waimea, on Kauai, and at Nonopapa, on Niihau.
V. Hypsometrical observations at Honolulu, Hilo, Kawaihae, Waimea, Kalaieha, and Waiau.

The location of these stations is shown in Illustration No. 23.

The gravity observations at Waikiki were made in connection with the International Geodetic Association work. The subsequent determinations were carried on with the cooperation of the Hawaiian Government Survey. The greater part of the expense was borne by this Bureau, and the personnel of the party was largely composed of members of the staff. Prof. W. D. Alexander, the accomplished surveyor-general of the islands, accompanied the expedition to the island of Hawaii and remained with us at all stations except Hilo. During the occupation of the summit of Mauna Kea he assumed the difficult task of making a trigonometrical survey of the plateau. The peaks have an altitude of nearly 14 000 feet and are composed largely of scoria and red volcanic sand, which makes the ascent one requiring extraordinary endurance. In this work he was assisted by Mr. J. M. Muir, who voluntarily accompanied the expedition without compensation and whose services were of great value. The other members of the party were Mr. W. E. Wall, Mr. E. D. Baldwin, and Mr. W. W. Chamberlain, of the Government Survey staff. Mr. Louis Koch performed the duties of steward, a service of some difficulty and of great importance to a party encamped above the clouds, and Kauwe, an intelligent Kanaka, acted as guide both during the ascent and on the return. In the computations I had the help of Mr. C. C. Yates during the latter part of the work.

PRELIMINARY AND CONCLUDING OBSERVATIONS AT WASHINGTON.

The gravity work of 1891–92 was entirely of a differential character. The continuous determinations at Waikiki simply required that the pendulums should receive no accident during the year of occupation, while the observations for the density of Mauna Kea only made it necessary to guard against accident between the times of swinging at the base and summit of the mountain. It is evident, however, that if the periods of oscillation of the three pendulums are determined in Washington before leaving on the expedition and again on the return an agreement of these two determinations will give increased confidence in all the work executed during the trip. In April 1891, the following values were found for the periods of oscillation of pendulums B_1, B_2, and B_3 at the Smithsonian Institution. They are reduced to



OUTLINE MAP
OF THE
HAWAIIAN ISLANDS
Showing the location of stations.

Class of Observations
+ Magnetic
○ Latitude
● " and Gravity
⌖ " " Magnetic
◆ " Gravity and Magnetic
✸ " " " Magnetic and Meteorological

a temperature of 15° C., a pressure of 500^{mm} at 0° C., to an infinitely small arc and sidereal time.

$$\left.\begin{aligned} B_1 &= 0{\cdot}500\ 782\ 8^s \\ B_2 &= 0{\cdot}500\ 696\ 2 \\ B_3 &= 0{\cdot}500\ 632\ 5 \end{aligned}\right\} \text{Mean} = 0{\cdot}500\ 703\ 8^s$$

Before the return of the expedition, in October, 1892, the base station at Washington had been transferred from the Smithsonian Institution to the Coast and Geodetic Survey Office. The periods were therefore determined at the latter place.

The following is the result:

$$\left.\begin{aligned} B_1 &= 0{\cdot}500\ 779\ 4^s \\ B_2 &= 0{\cdot}500\ 695\ 0 \\ B_3 &= 0{\cdot}500\ 631\ 3 \end{aligned}\right\} \text{Mean} = 0{\cdot}500\ 701\ 9^s$$

A comparison of the above values gives a diminished period for all three pendulums. We have the excess of the time of oscillation in April, 1891, at the Smithsonian Institution, over that in December, 1892, at the Coast and Geodetic Survey Office, as follows:

$$\left.\begin{aligned} \text{For } B_1 &= +\ 0{\cdot}000\ 003\ 4^s \\ B_2 &= +\ 0{\cdot}000\ 001\ 2 \\ B_3 &= +\ 0{\cdot}000\ 001\ 2 \end{aligned}\right\} +\ 0{\cdot}000\ 001\ 9^s$$

These two stations were connected by simultaneous determinations of gravity by Mr. Putnam and Mr. Von der Trenck. The result gave an excess of the period at the Coast and Geodetic Survey Office over that at the Smithsonian Institution of $0{\cdot}000\ 000\ 5^s$. So that we have a mean decrease in the period of oscillation of the *B* pendulums consequent upon the work outside of the United States of $0{\cdot}000\ 002\ 4^s$. This is about 1 part in 400 000. When we consider that these pendulums were in continual service for more than a year at Waikiki, that they were transported on mule back to an elevation of over 13 000 feet, where the observations were made under difficult and adverse circumstances, and that numerous other stations were occupied in the Hawaiian Islands and in this country, this close agreement between the periods of oscillation before and after the expedition must be regarded as highly satisfactory.

In regard to the accuracy attainable in the general method of optical coincidences as practiced in this work, it appears to be far beyond what is necessary. If $c =$ the interval in seconds between two coincidences, and if in that time the pendulum has gained or lost one beat on the timepiece, the time (t) of one oscillation is

$$\frac{c}{2c \pm 1}$$

The accuracy with which t is determined depends both on the length of the interval and the rate of the pendulum on the timepiece, but principally on the former. Differentiating the above expression gives approximately

$$dt = \frac{\pm\, dc}{4c^2}$$

Where the pendulum period is nearly an aliquot part of that of the timepiece and the interval between two coincidences is 15 minutes, or say 1 000 seconds, an observation of c to the nearest second will only produce an error in the length of the period of one part in eight million.

The following are the observations at Washington before and after the expedition. The computations, as well as the observations, were made by Mr. G. R. Putnam, Assistant Coast and Geodetic Survey. The arc corrections were computed by Borda's formula. The temperature coefficient was determined empirically by observations at high and low temperatures in April, 1891. The increase in period for 1° C. increase in temperature was found to be:

For pendulum B_1	$0{\cdot}000\,004\,16^s$
B_2	4 22
B_3	4 08

The mean of these, which is $0{\cdot}000\,004\,15^s$, was used in the reductions. From the coefficient of expansion of the pendulum alloy, as determined by the Office of Standard Weights and Measures, we get $0{\cdot}000\,004\,14^s$.

The pressure coefficient was determined in April, 1891. The mean for the three pendulums was found to be $0{\cdot}000\,000\,078\,9^s$, representing the increase in period for an increase of 1^{mm} in pressure at 0° C.

The correction to the period is therefore.

$$-K\left[\frac{P}{1+0.00367t}-500\right]$$

where P is the difference between the readings of the barometer and manometer and t is the temperature. This reduces the period to that at a pressure of 500^{mm} at 0° C.

The chronometer rates were.determined in April, 1891, from United States Naval Observatory signals, and in December, 1892, by time observations, by Mr. Putnam.

The gravity work for all the stations is published according to the following scheme:

Column I indicates the pendulum.

Column II, the position (direct or reverse.

Column III, the number of the swing.

Column IV, the date.

Column V, the number of seconds between the first and eleventh coincidence.

Columns VI and VII indicate the arc through which the pendulum was swinging at the first and eleventh coincidence.

Column VIII indicates the corrected temperature.

Column IX, the manometer reading.

Column X, indicates the barometer reading.

Column XI, the pressure in the receiver at a temperature of 0° C.

The uncorrected periods, the different corrections, and finally the corrected period in sidereal time are given in the following table:

Pendulum observations, Washington, D. C. (Smithsonian Institution).

[Observer: G. R. Putnam.]

Pendulum.	Position.	Swing.	Date.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
					Initial.	Final.				
			1891.	*Seconds.*	*mm.*	*mm.*	°*C.*	*mm.*	*mm.*	*mm.*
B_1	D	1	Apr. 15	3267·0	5·35	3·85	20·93	224·2	765·1	500·6
		2	15	3266·0	5·25	3·85	20·98	223·0	765·3	501·9
		13	16	3271·0	5·85	4·10	20·93	228·6	768·7	499·9
		19	16	3260·0	5·30	3·80	21·08	228·4	766·9	498·3
B_1	R	3	15	3252·5	5·20	3·80	21·08	226·5	765·3	498·4
		4	15	3257·0	5·35	3·80	21·18	225·5	765·3	499·1
		14	16	3260·0	5·70	3·90	20·93	229·0	768·3	499·2
		22	16	3261·8	5·25	3·20	21·10	226·2	767·8	501·0
B_2	D	5	15	3645·0	5·30	3·55	21·28	203·7	765·0	519·0
		6	15	3653·0	5·40	3·85	21·36	227·2	764·6	496·7
		15	16	3600·0	5·30	3·65	20·98	229·4	767·7	498·2
		20	16	3662·0	5·30	3·75	21·08	231·0	765·5	496·3
B_2	R	7	15	3666·5	5·20	3·70	21·40	226·7	764·4	496·9
		8	15	3670·0	5·30	3·75	21·40	224·8	764·3	498·6
		16	16	3681·0	5·25	3·75	21·06	229·4	767·2	497·6
		23	17	3708·0	5·25	3·50	20·57	215·4	770·2	514·2
B_3	D	9	15	4042·5	5·20	3·25	21·40	224·6	764·4	498·8
		10	16	4044·5	5·35	3·75	20·74	227·7	769·2	501·5
		17	16	4054·5	5·00	3·20	21·08	228·2	766·9	498·4
		21	16	4047·0	5·00	3·20	21·10	230·0	767·8	497·5
B_3	R	11	16	4054·5	5·30	3·60	20·81	227·2	769·1	501·8
		12	16	4053·5	5·30	3·70	20·88	230·0	769·0	498·9
		18	16	4050·5	4·85	3·25	21·10	228·1	766·8	498·4
		24	17	4099·5	4·80	3·20	20·59	234·8	770·1	495·9

Reduction of pendulum observations, Washington, D. C. (Smithsonian Institution).

[Periods reduced to temperature, 15° C; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Pendulum.	Swing.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
			Arc.	Temperature.	Pressure.	Rate.	
		Seconds.					*Seconds.*
B_1	1	0·500 7664	—74	—246	0	+486	0·500 7830
	2	7666	—73	—248	— 1	+486	7830
	13	7655	—86	—246	0	+457	7780
	19	7680	—73	—252	+ 1	+468	7824
						Direct	0·500 7816
B_1	3	0·500 7698	—71	—252	+ 1	+486	0·500 7862
	4	7688	—74	—256	+ 1	+486	7845
	14	7680	—81	—246	+ 1	+468	7822
	22	7676	—62	—253	— 1	+468	7828
						Reverse	0·500 7839
						Mean	0·500 7828
B_2	5	0·500 6868	—68	—261	—15	+486	0·500 7010
	6	6853	—75	—264	+ 3	+457	6974
	15	6829	—70	—248	+ 1	+468	6980
	20	6836	—72	—252	+ 3	+468	6983
						Direct	0·500 6987
B_2	7	0·500 6828	—70	—266	+ 2	+457	0·500 6951
	8	6821	—72	—266	+ 1	+457	6941
	16	6801	—71	—251	+ 2	+468	6949
	23	6751	—67	—231	—11	+468	6910
						Reverse	0·500 6938
						Mean	0·500 6962
B_3	9	0·500 6192	—62	—266	+ 1	+457	0·500 6322
	10	6189	—73	—238	— 1	+457	6334
	17	6174	—59	—252	+ 1	+468	6332
	21	6185	—59	—253	+ 2	+468	6343
						Direct	0·500 6333
B_3	11	0·500 6174	—69	—241	— 1	+457	0·500 6320
	12	6175	—71	—244	+ 1	+457	6318
	18	6180	—57	—253	+ 1	+468	6339
	24	6106	—56	—232	+ 3	+468	6289
						Reverse	0·500 6316
						Mean	0·500 6324

Pendulum observations, Washington, D. C. (Coast and Geodetic Survey Office).

[Observer: G. R. Putnam.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semiarc.		Temperature.	Manometer.	Barometer.	Pressure at 0°C.
						Initial.	Final.				
			1892.		*Seconds.*	*mm.*	*mm.*	°*C.*	*mm.*	*mm.*	*mm.*
B$_1$	D	13	Dec. 14	14	3295·4	5·35	3·50	12·00	232·9	764·6	508·3
		14	15	10	3297·0	5·35	4·00	11·88	239·6	767·4	504·8
		15	15	10	3296·5	5·30	3·95	11·93	239·3	767·4	505·0
		16	15	10	3295·5	5·25	3·80	11·97	237·6	766·8	505·9
		31	17	16	3292·2	5·40	3·25	12·40	237·7	762·4	500·9
		32	18	10	3294·5	5·30	3·95	11·95	240·0	763·8	500·9
B$_1$	R	17	15	10	3281·5	5·15	3·85	12·17	216·4	765·8	525·0
		18	15	10	3287·5	5·25	3·80	12·35	246·8	765·5	495·3
		19	15	10	3283·5	5·30	3·80	12·45	244·2	765·4	497·5
		33	18	6	3296·7	5·20	4·35	11·83	239·4	761·5	499·4
		34	18	12	3297·9	5·30	3·70	11·83	237·5	761·5	501·2
B$_2$	D	7	14	10	3729·0	5·40	3·80	11·20	241·5	762·6	499·6
		8	14	10	3725·0	5·40	4·00	11·30	243·1	762·8	498·2
		9	14	10	3723·0	5·40	3·90	11·40	240·4	762·5	500·2
		26	17	10	3706·0	5·35	3·80	11·93	242·8	761·9	496·4
		27	17	10	3705·0	5·30	3·80	11·95	240·0	761·6	498·8
		28	17	10	3704·5	5·30	3·80	12·00	239·2	761·0	498·9

Reduction of pendulum observations, Washington, D. C. (Coast and Geodetic Survey Office).

[Periods reduced to temperature 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Pendulum.	Swing.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
			Arc.	Temperature.	Pressure.	Rate.	
		Seconds.					*Seconds.*
B_1	13	0·500 7598	—68	+124	— 6	+152	0·500 7800
	14	7594	—77	+129	— 4	+142	784
	15	7595	—75	+127	— 4	+142	785
	16	7598	—72	+126	— 5	+142	789
	31	7606	—65	+108	— 1	+144	792
	32	7600	—75	+126	— 1	+145	795
						Direct	0·500 7791
B_1	17	0·500 7630	—71	+117	—20	+142	0·500 7798
	18	7616	—72	+110	+ 4	+142	800
	19	7625	—73	+106	+ 2	+142	802
	33	7595	—80	+132	0	+145	792
	34	7592	—71	+132	— 1	+145	797
						Reverse	0·500 7798
						Mean	0·500 7794
B_2	7	0·500 6713	—74	+158	0	+162	0·500 6959
	8	6720	—78	+154	+ 1	+162	959
	9	6724	—76	+149	0	+162	959
	26	6755	—74	+127	+ 3	+143	954
	27	6757	—73	+126	+ 1	+143	954
	28	6758	—73	+124	+ 1	+143	953
						Direct	0·500 6956

Pendulum observations, Washington, D. C. (Coast and Geodetic Survey Office).

[Observer: G. R. Putnam.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
						Initial.	Final.				
			1892.		*Seconds.*	*mm.*	*mm.*	*°C.*	*mm.*	*mm.*	*mm.*
B_2	R	10	Dec. 14	10	3730·5	5·35	3·65	11·50	243·6	762·2	496·7
		11	14	10	3726·0	5·25	3·75	11·67	241·7	762·4	498·4
		12	14	10	3723·5	5·20	3·80	11·77	244·0	762·7	496·3
		29	17	10	3713·0	5·30	3·90	12·13	244·0	760·0	493·0
		30	17	10	3709·5	5·30	3·80	12·27	241·1	760·0	495·6
B_3	D	1	12	12	4122·1	5·90	3·60	11·45	235·2	774·9	517·0
		2	13	10	4143·5	5·25	3·40	10·90	241·5	772·6	509·7
		3	13	10	4145·5	5·20	3·45	10·97	252·4	771·9	498·4
		20	15	14	4092·9	5·10	3·10	12·55	240·0	766·6	502·4
		21	16	10	4096·5	4·85	3·30	12·23	244·8	767·9	499·7
		22	16	12	4096·2	4·90	3·15	12·27	241·6	767·8	502·5
B_3	R	4	13	10	4125·0	4·85	3·30	11·13	239·6	770·7	509·2
		5	13	10	4129·0	4·85	3·30	11·25	254·9	769·8	493·6
		6	13	10	4125·0	4·85	3·30	11·33	246·7	769·2	500·7
		23	16	10	4083·5	4·85	3·30	12·40	243·5	766·8	499·6
		24	16	10	4081·0	4·85	3·30	12·45	241·4	766·5	501·2
		25	16	10	4080·0	4·85	3·30	12·45	239·6	766·4	502·8

Reduction of pendulum observations, Washington, D. C. (Coast and Geodetic Survey Office).

[Periods reduced to temperature 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Pendulum.	Swing.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
			Arc.	Temperature.	Pressure.	Rate.	
		Seconds.					*Seconds.*
B_2	10	0·500 6710	—71	+145	+ 3	+162	0·500 6949
	11	6719	—71	+138	+ 1	+162	949
	12	6723	—71	+134	+ 3	+162	951
	29	6742	—74	+119	+ 6	+143	936
	30	6748	—73	+113	+ 3	+143	934
						Reverse	0·500 6944
						Mean	0·500 6950
B_3	1	0·500 6072	—78	+147	—13	+162	0·500 6290
	2	6041	—65	+170	— 8	+162	300
	3	6038	—65	+167	+ 1	+162	303
	20	6116	—58	+102	— 2	+142	300
	21	6110	—58	+115	0	+143	310
	22	6111	—56	+113	— 2	+143	309
						Direct	0·500 6302
B_3	4	0·500 6068	—58	+161	— 7	+162	0·500 6326
	5	6062	—58	+156	+ 5	+162	327
	6	6068	—58	+152	— 1	+162	323
	23	6130	—58	+108	0	+143	323
	24	6134	—58	+106	— 1	+143	324
	25	6135	—58	+106	— 2	+143	324
						Reverse	0·500 6324
						Mean	0·500 6313

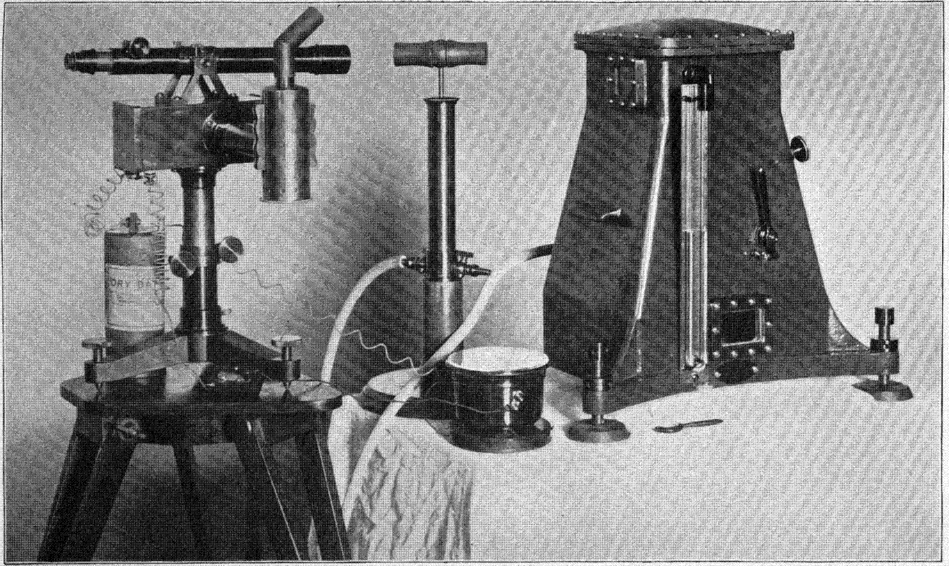
GRAVITY OBSERVATIONS AT WAIKIKI.

For a description of this station it will be sufficient to refer to Appendix No. 2, Report of Coast and Geodetic Survey for 1892. The pendulum apparatus has been described by Mr. G. R. Putman in a special report by the Superintendent on the "Determination of gravity," Appendix No. 15, Report of Coast and Geodetic Survey for 1891. This paper may be consulted for all details of construction and manipulation. A general view of the apparatus is shown in illustration No. 24.

The observations for the force of gravity at Waikiki were begun on June 9, 1891, and continued until June 11, 1892. During this time 199 nights' work were obtained. The determinations were limited to those nights on which satisfactory star observations could be made, and the pendulum was swung during the time that the regular international latitude investigations were carried on. This made the duration of the swings somewhat variable, but the pendulum in nearly every case was allowed to oscillate for several consecutive hours. The plan generally followed was this: In the early evening, after one or two pairs of stars had been obtained for latitude, one circumpolar and several time stars were observed with the instrument in the position "clamp west." The pendulum was then started, after which the meridian telescope was reversed to the position "clamp east" and a few more stars taken. A circumpolar was obtained in the second position when possible, but this was not considered essential. The advantage of the foregoing scheme is that the pendulum apparatus has time to take the evening temperature before beginning the swing, and that the beginning of the swing is referred to the epoch of the reversal of the instrument. The telescope was allowed to remain with "clamp east" until the close of the night's work, when another half set was observed.

Inasmuch as we desire only differential rates for the chronometer, we have here the corrections determined before and after the swing almost entirely independent of the instrumental constants. The effect of azimuth was entirely eliminated by observing stars north and south of the zenith. The level was directly observed, but since the instrument was not reversed during the swing, the change was inappreciable, and whatever the collimation, as there was no reversal, its effect on the difference of the clock corrections is insignificant.

The instrumental constants were quite small during the entire year. Moreover, since the same stars were observed from night to night the chronometer rates are independent of any errors in the right ascensions. It is believed that this work reaches all the accuracy attainable with this set of instruments. The arrangement of the time observations, the method employed of interchanging the pendulums, and the precautions taken in the temperature and pressure conditions seem to exhaust the precision of manipulation, so that any discrepancies must be attributed either to the construction of the instruments or to real



HALF-SECOND PENDULUM APPARATUS.

Side view (right) of receiver, flash apparatus, etc.

differences in the force of gravity. The principal defect in the apparatus was in the means of reading the amplitude of oscillation. At the beginning of the swing the half amplitude was usually about 1°, or a distance of 5^{mm} on the scale at the pendulum point, which is 297^{mm} below the knife edge. After an hour and a half this half amplitude had decreased to about $0^{\circ}{\cdot}5$ or to 3^{mm}, and the correction to reduce the time of one oscillation to what it would have been in an infinitely small arc is $0{\cdot}000\ 005\ 6^{s}$. Now, an error of one-tenth of a millimetre in estimating the amplitude would produce an error of rather more than one ten-millionth of a second in the correction for arc, so that we may assume that the uncertainties arising from the scale readings do not materially affect the deduced period as much as the millionth part of a second.

The change of gravity for a small change in the latitude of the place may be obtained by differentiating the equation

$$g = C + D \sin^2 \varphi$$

where C is the force of gravity at the equator, and D is the increase in this force in passing from the equator to the pole, the unit being taken in metres. For a value of $\varphi = 21^{\circ}\ 16'$ we get

$$dg = 0{\cdot}0338\ d\varphi$$

A change, therefore, of $1''$ in the latitude would give a change of $\frac{0{\cdot}0338}{206\ 000}$ or $\frac{1}{6\ 100\ 000}$ of a metre in the value of $D \sin^2 \varphi$ or about $\frac{1}{60\ 000\ 000}$ of the total force of gravity.

The change of latitude at Waikiki during the entire year being six-tenths of a second, the force of gravity would not be disturbed from this cause more than 1 part in 100 000 000.

The following table contains the chronometer corrections and instrumental constants from June 4, 1891, to June 11, 1892. The value of the collimation is given with its appropriate sign for the position of the telescope with the clamp on the west side. The azimuths are given for those positions in which a determination was made. When no stars of sufficiently high declination could be obtained to bring out this constant, that of a preceding or following day was used and the corresponding tabular space is left vacant.

Clock rates and instrumental constants, Waikiki, Hawaiian Islands.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1891.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
June 4	13	30	+2	9·92	6·60	+0·06	+0·19	
6	16	00		23·82	7·06	— ·09		—0·22
9	15	40		44·90	7·34	+ ·07	— ·62	
10	15	45		52·24	7·40	— ·09	— ·62	
11	15	30		59·57	7·37	— ·18	+ ·15	— ·42
12	15	30		6·94	6·88			
13	14	30	+3	13·54	6·24	— ·25	— ·07	+ ·05
15	14	30		26·02	6·67	— ·55	— ·59	— ·80
16	13	15		32·37	6·43		+ ·71	
17	14	30		39·14	6·67	·00	+ ·58	+ ·13
18	14	30		45·81	6·97	— ·23		+ ·42
19	14	30		52·78	6·60	+ ·09	+ ·12	— ·01
22	14	30	+4	12·58	6·68	— ·16		— ·16
24	15	30		26·21	6·16	+ ·12	— ·05	+ ·33
25	16	30		32·62	6·58	+ ·18		
26	15	25		38·93	6·89	+ ·16		+ ·28
27	14	30		45·53	6·61	+ ·17	+ ·06	
28	15	30		52·42	6·36	+ ·05		·00
30	14	30	+5	4·89		+ ·10	+ ·37	
July 4	16	10	—2	29·29	6·64		+ ·30	
7	18	00		8·87	6·36	+ ·10		— ·22
8	17	50		2·56	7·04	+ ·21	+ ·04	
17	18	30	—0	59·20	7·15	+ ·22	— ·14	
18	17	50		52·26	7·20	+ ·27	— ·26	— ·60
22	18	30		23·26	6·59	+ ·27		
23	17	45		16·86	6·76	— ·15	+ ·41	
24	17	45		10·10	6·90	— ·11		— ·05
25	18	30		2·99	7·76			
26	18	00	+0	4·62	7·25	— ·03	+ ·03	+ ·04
27	17	45		11·80	7·19	— ·08	+ ·21	
29	17	45		26·18	6·63	— ·03	— ·12	
30	19	00		33·16	6·79	— ·10	+ ·13	
31	17	45		39·60	6·50	·00	— ·12	·00
Aug. 2	18	15		52·71	6·25	— ·07	+ ·01	+ ·13
3	18	15		58·96	6·57	— ·21	+ ·22	+ ·19
4	17	45	+1	5·40	6·93	— ·11	+ ·23	+ ·33
5	17	30		12·26	6·97	— ·14	+ ·25	+ ·33
6	18	00		19·38	7·09	+ ·04	+ ·21	+ ·06
7	17	45		26·40	7·24	+ ·05	+ ·34	+ ·32
10	17	30		48·07	7·14	+ ·04	*— ·57	— ·36
11	17	45		55·28	7·34	— ·05	— ·49	— ·40
13	17	30	+2	9·91	7·11	— ·04	— ·42	— ·32
14	17	30		17·02	7·02	+ ·05	— ·31	·00
15	17	30		24·04	6·96	+ ·05	— ·23	— ·31
16	17	30		31·00	6·76	— ·03	— ·14	— ·38
20	19	30		58·04	6·19	+ ·10	— ·37	— ·22
22	19	30	+3	10·42	6·13	+ ·05	·00	— ·19
23	19	30		16·55	6·16	+ ·07	— ·15	— ·38
25	22	00		29·52	6·34	— ·07	— ·37	
26	19	00		35·07	6·04	— ·06	— ·18	
29	19	00		53·20		— ·08		+ ·11
	22	30		54·06	6·53			+ ·12
31	19	00	+4	6·26		— ·07	— ·45	— ·07

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*On August 8 telescope moved eastward.

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1891.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
Sept. 2	19	00	—2	40·30	6·47	— ·12	— ·07	— ·17
6	19	00		14·43		·00	— ·42	— ·22
	20	00		14·03	6·15			
9	19	00	—1	55·59	6·19	— ·05	— ·33	— ·28
12	19	00		37·02	6·28	— ·07	— ·30	— ·22
15	19	00		18·18	6·48	— ·06	— ·36	— ·33
17	20	30		4·83	6·61	— ·03	— ·47	— ·22
18	19	00	—0	58·63	6·35	— ·02	— ·41	— ·22
19	19	00		52·28	6·40	— ·12	— ·37	— ·26
23	21	00		26·17	6·61	— ·05	— ·32	
26	19	00		6·84	6·51	— ·09	— ·20	— ·29
27	20	00	—0	0·06	6·61	— ·09		— ·42
28	19	00	+0	6·28				
Oct. 4	22	30		46·65		— ·20		— ·60
	22	34		46·58	6·43			
	2	13		47·46				
5	22	30		53·08		— ·20		— ·60
	22	34		53.00	6·56			
	2	13		53·88			— ·27	
8	22	30	+1	12·75		— ·10		— ·60
	22	34		12·79	6·41		— ·43	
	2	15		13·80				
10	22	30		25·57		— ·08		+ ·70
	22	34		25·56	6·60			
	0	00		26·07			+ ·09	
14	22	30		51·97	6·51	+ ·11	+ ·13	— ·11
16	22	30	+2	4·99		+ ·13	+ ·20	+ ·13
	22	33		4·98	6·60			
	2	15		5·99				
22	22	30		44·60		+ ·09		+ ·10
	22	55		44·61	6·53			
	1	00		45·20				
28	22	30	+3	23·80		— ·04		— ·31
	22	54		23·80	6·73			
	2	04		24·53				
30	22	30		37·26		+ ·12	+ ·15	+ ·10
	22	31		37·26	6·54			
	2	15		38·24				
31	22	30		43·80		— ·12		+ ·10
	22	32		43·81	6·38			
	2	15		44·78				
Nov. 1	22	30	—3	9·82		— ·04	+ ·07	+ ·08
	22	38		9·82	6·33			
	2	15		8·84				
4	22	30	—2	50·82		— ·04	— ·06	
	22	38		50·82	6·33			
	2	15		49·84				
6	22	30		38·16		— ·04	— ·22	— ·32
	22	37		38·16	6·49			
	2	15		37·06				
7	22	30		31·67	6·05			
8	23	00		25·50		— ·10	— ·25	— ·28
	23	02		25·49	6·29			
	1	30		24·90				

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1891.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
Nov. 12	1	00	—1	59·86	6·38	·00	·00	+ ·35
13	22	30		54·14		— ·12	+ ·30	·00
	22	37		54·13	6·40			
	2	15		53·21				
14	22	30		47·74		— ·10	+ ·22	+ ·05
	22	37		47·78	6·62			
	2	15		46·74				
17	22	30		27·86		— ·03	— ·01	+ ·12
	22	36		27·86	6·90			
	2	15		26·75				
19	0	30	—1	13·45	6·52	+ ·13	+1·97	+1·75
	5	30		12·10				
	5	44		12·08				
21	0	30		00·40				+ ·42
	0	35		00·45	6·61			
	5	30	—0	59·00		+ ·20		
22	1	30		53·51	6·48	+ ·14	+ ·18	+ ·47
23	1	00		47·16	6·59	+ ·12	·00	+ ·27
28	1	00		14·22	6·70	[— ·04	From Nov. 30	+ ·21]
30	0	30		00·96		— ·04	+ ·67	+ ·21
	0	36		00·85	6·42			
	5	30	+0	00·11				
Dec. 1	0	30		05·46				+ ·22
	0	36		05·45	6·43			
	5	30		06·36			+ ·55	
5	1	00		31·32				+ ·41
	5	30		32·55	6·43	+ ·15		
	5	32		32·55				
6	0	30		37·63	6·60	+ ·15	From Dec. 5	+ ·44
7	1	00		44·36	6·51	— ·05	+ ·57	+ ·33
9	0	30		57·26				
	0	35		57·28	6·45			
	5	30		58·52		— ·08	— ·06	+ ·25
10	0	30	+1	03·71	6·34			·00
11	1	00		10·17	6·61	+ ·15	+ ·26	— ·11
12	1	00		16·78				
	0	33		16·78	6·35			
	5	30		17·99		— ·06	— ·36	— ·20
15	1	00		35·84				
	1	34		35·83	6·34			
	5	30		37·10		— ·24	— ·40	— ·53
17	0	30		48·38	6·15			+ ·11
19	0	30	+2	00·68		+ ·11		— ·09
	0	34		00·77	5·93			
	5	30		02·00			·00	
20	0	30		06·61	6·35			
21	0	30		12·96	6·00			
22	0	30		18·96	6·26			
23	0	30		25·22		+ ·20		— ·30
	0	33		25·21	6·67			
	5	30		26·74			— ·31	
24	0	30		31·89	6·58			— ·15
25	0	30		38·47		+ ·08	+ ·15	+ ·06
	0	38		38·48	6·43			
	5	30		39·82				

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1891.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
Dec. 26	1	30	+2	45·17				·00
	5	30		46·46	6·62	+0·17	—0·31	
	5	40		46·48				
27	0	30		51·52	6·48			— ·10
28	0	30		58·00				— ·16
	0	31		58·00	6·42			
	5	30		59·24		+ ·09	— ·32	
29	0	30	+3	04·42				— ·22
	0	31		04·42	5·88			
	5	30		05·62		+ ·04	— ·19	
30	0	30		10·30				+ ·16
	0	33		10·29	5·82			
	5	30		11·42		+ ·05	+ ·17	
1892.								
Jan. 1	0	30		21·94	5·75			+ ·13
2	0	30	—3	32·31	6·01			+ ·14
3	0	30		26·30	5·77			
5	1	00		14·64		+ ·02		+ ·17
	1	38		14·64	5·59			
	5	30		13·66			— ·10	
6	5	00		08·12	5·52	+ ·26		·00
10	5	00	—2	46·04	5·59	+ ·10		
11	5	30		40·34				
	5	46		40·36	5·71			
	7	30		39·85		+ ·10	+ ·20	
12	5	30		34·63				
	5	46		34·62	5·49			
	8	00		34·00		[+ ·12]	+ ·15	
16	5	30		12·66	5·83	+ ·07		+ ·40
18	5	00		01·11				— ·26
	8	00		00·58	5·79	[— ·10]		
19	5	00	—1	55·32	6·06	[— ·10]		[— ·20]
20	5	00		49·26				
	8	00		48·70	5·62	— ·10	— ·14	
	8	14		48·69				
21	5	00		43·64				
	5	02		43·60	5·26			
	8	00		42·97		— ·10		+ ·08
23	5	00		33·12				— ·25
	5	02		33·14	5·40			
	8	00		32·50		— ·10		
24	5	00		27·72				
	4	57		27·71	5·82			
	8	00		27·00		— ·08	+ ·41	— ·14
25	5	00		21·90				
	8	00		20·84	6·43			
	8	05		20·84				
27	5	00		09·04				— ·21
	8	00		08·33	5·87			
	8	40		08·30		+ ·02		— ·21
Feb. 2	8	00	—0	33·12				
	8	00		33·13		— ·13		
3	5	00		28·26	5·50			— ·10
	4	56		28·26				

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1892.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
	8	00	—0	27·63	5·75	—0·04		
Feb. 4	5	00		22·51				—0·11
	8	00		21·72	5·93	— ·04	·00	
	8	41		21·72				
6	5	00		10·64				
	8	00		09·92	5·86			
	8	41		09·83		+ ·02		·00
8	5	00	+0	01·08				
	8	00		01·85	5·47	·00		+ ·16
	8	41		01·86				
12	5	00		22·94				
	5	30		22·82	5·24			
	8	00		23·62		·00		+ ·13
13	5	00		28·18				— ·23
	5	22		28·24	5·13			
	8	00		28·84		— ·03		
14	5	00		33·31				
	4	55		33·32	4·94			
	8	00		34·11				— ·10
19	7	30		58·51	5·02	·00		
20	5	00	+1	03·01	5·01	·00		+ ·06
21	5	00		08·02				— ·05
	4	55		08·02	5·07			
	8	00		08·51		·00	— ·46	
22	5	00		13·09	4·98	— ·05		·00
23	5	00		18·07				
	4	55		18·07	5·47			
	8	00		18·72		— ·05		+ ·05
26	7	30		35·06	5·82	— ·16	·00	
27	7	30		40·88				
	7	37		40·88	6·01			
	12	00		41·89		— ·07		
28	7	30		46·89				
	8	10		46·89	6·02			
	11	30		47·80		— ·05	+ ·30	
29	7	30		52·91				
	7	40		52·90	5·91			
	11	30		53·81		— ·07	+ ·32	
Mar. 1	7	30	—3	01·18				
	7	41		01·19	5·74			
	9	00		00·84		— ·05	+ ·23	
2	7	30	—2	55·44				
	7	41		55·44	5·99			
	11	30		54·55		— ·05	·00	
4	7	30		43·45	6·07	— ·07		
5	7	30		37·38				
	7	41		37·38	5·88			
	11	30		36·41		— ·03	·00	
8	10	30		19·00	5·91	— ·03		+ ·48
9	7	30		13·82				
	7	41		13·81	6·17			
	11	30		12·84		— ·03	+ ·21	
10	7	30		07·65		— ·05	+ ·38	
	7	40		07·64				
	11	30		06·68	5·77			

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.	Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
							E.	W.
1892.	*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
Mar. 13	7	30	—1	50·33	5·88	—0·02	[+0·40]	
14	7	30		44·45	5·82	— ·05	[+ ·40]	
16	7	30		32·81	5·71	·00	·00	
19	7	30		15·67	5·70	— ·06	+ ·25	
20	7	30		09·97	5·91	— ·04	[+ ·25]	
21	7	30		04·06				
	7	39		04·07	5·82			
	12	00		02·93		— ·04	[+ ·25]	
23	9	00	—0	52·05				+0·70
	9	07		52·05	5·76			
	12	00		51·52		— ·12	+ ·50	
24	7	30		46·66		— ·04	+ ·30	
	7	39		46·65	5·79			
	11	30		45·76				
29	7	30		17·73				
	7	39		17·72	5·77			
	11	30		16·88		+ ·26	+ ·70	
30	7	30		11·96		+ ·25		
	7	38		11·98	5·86			
	11	30		11·06			+ ·54	
31	7	30		06·10		·00		
	7	38		06·11	5·79			
	11	30		05·28			+ ·54	
Apr. 6	10	15	+1	29·39	5·78			— ·20
9	10	15		46·73				
	14	45		47·74	5·85	+ ·12	— ·40	— ·18
	14	58		47·73		[+ ·10]		
10	10	15		52·58	5·86	[+ ·10]		
13	10	30		10·25	5·87	[+ ·10]		— ·18
14	10	30		16·12	5·95	[+ ·10]		— ·10
15	10	30		22·07	6·05	[+ ·10]		— ·16
16	10	30		28·12				
	14	45		29·14	5·91			
	14	57		29·17		+ ·08	— ·65	— ·68
17	10	15		33·98				
	10	13		33·98	5·95			
	12	45		34·58		[+ ·12]		— ·30
18	11	30		40·23	5·81	[+ ·16]		— ·43
19	10	30		45·80				
	14	45		46·90	5·93			
	14	57		47·90		+ ·20	— ·67	— ·60
20	10	15		51·66	6·08			— ·18
	11	45		52·08		[+ ·20]		— ·33
21	10	15		57·74	5·99	[+ ·18]		— ·30
23	10	15	+2	09·71				
	14	45		11·04	6·08	+ ·15		— ·60
	14	56		11·09				
24	10	15		15·79				
	14	45		16·90	5·77	+ ·12	— ·84	— .38
	14	56		16·89				
25	10	15		21·56				
	14	45		22·73	5·75	+ ·20		— ·35
	14	56		22·80				
29	10	15		44·57	5·86	+ ·20		— ·10
May 1	10	45		56·42				

Clock rates and instrumental constants, Waikiki, Hawaiian Islands—Continued.

[Negus sidereal chronometer No. 1825. Observer: E. D. Preston.]

Date.		Epoch (sidereal time).		Correction.		Daily rate.	Collimation W.	Azimuth.	
								E.	W.
1892.		*h.*	*m.*	*m.*	*s.*	*Seconds.*	*Seconds.*	*Seconds.*	*Seconds.*
May	1	14	45	+2	57·17	5·48	+0·16	—0·43	—0·04
		14	52		57·19				
	2	10	15	—2	58·21	5·66	[+ ·15]		— ·13
	4	10	15		46·80				
		14	45		45·70	5·90	+ ·15	+ ·06	+ ·22
		14	50		45·69				
	5	10	15	—2	40·90				
		14	45		39·90	5·87	+ ·07	·00	+ ·34
		14	56		39·88				
	6	10	15		35·03	6·09	+ ·07		+ ·20
	7	11	15		28·69	5·78			
	9	10	15		17·37				
		14	45		16·22	5·98	+ ·08	+ ·07	+ ·30
		14	50		16·23				
	10	10	15		11·39				
		14	45		10·44	5·64	+ ·08		+ ·32
		10	17		11·42				
	11	10	15		05·75	5·76	+ ·08		+ ·07
	13	12	15	—1	53·74				+ ·25
		14	45		53·15	5·92	+ ·06	·00	
		15	00		53·12				
	14	10	15		48·31				— ·22
		14	45		47·17	5·67	+ ·07	— ·20	
		15	00		47·10				
	15	10	15		42·64				— ·16
		14	45		41·45	5·84	+ ·16	— ·40	
		15	00		41·43				
	18	10	15		25·13				— ·07
		14	45		24·10	5·80	+ ·07	— ·27	
		15	00		24·10				
	21	11	45		07·37				— ·20
		14	45		06·53	5·97	+ ·15	— ·30	
		15	00		06·45				
	22	11	15		01·51				— ·50
		14	45		00·58	5·80	+ ·11	— ·16	
		15	00		00·55				
	23	14	45	—0	54·87	5·87	+ ·23	— ·51	— ·13
	24	14	45		49·00	5·76	+ ·12	— ·09	+ ·09
	25	14	00		43·46				
		17	45		42·50	5·74	+ ·11	— ·12	— ·13
		17	57		42·51				
	27	14	45		31·80	5·76	+ ·08	+ ·13	+ ·20
	28	14	00		26·23				
		17	45		25·41	5·80	+ ·10	— ·16	+ ·10
		17	58		25·38				
	29	14	45		20·26	5·69	+ ·04	— ·22	
June	3	14	00	+0	07·97	5·67	[+ ·10]		— ·06
	4	14	00		13·64				·00
	5	14	00		19·39	5·75	+ ·10		·00
	6	14	00		25·24	5·85			
	7	14	00		31·00	5·76			+ ·07
		17	45		31·99	5·89	+ ·18	— ·33	
		18	02		31·98				
	11	14	00		54·57				+ ·11
		17	45		55·45		+ ·11	— ·31	
		18	02		55·44				

The following table contains the Pendulum Results for 199 nights at Waikiki between June 9, 1891, and June 11, 1892:

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	June 9	14·1	24	6296·0	2623·3	5·0	2·5	26·33	206·0	767·2	510
		10	14·0	20	5256·0	2628·0	5·2	2·5	25·98	206·0	767·4	511
		10	15·7	20	5280·0	2640·0	5·2	2·5	24·92	200·0	767·4	519
		11	13·9	20	5282·0	2641·0	5·2	3·0	25·43	212·5	768·0	507
		11	15·7	20	5303·5	2651·8	5·2	2·7	24·62	205·0	767·6	515
		12	14·2	32	8440·0	2637·5	5·2	[2·1]	25·47	211·0	767·4	508
		13	14·6	44	11588·0	2633·6	5·2	1·2	25·42	208·0	766·4	510
		15	14·3	32	8416·5	2630·2	5·1	2·0	25·73	217·0	766·8	501
		16	14·7	20	5244·5	2622·2	5·2	2·5	26.33	214·0	767·6	503
		17	14·9	30	7895·5	2631·8	[5·1]	2·0	26·13	219·0	767·5	499
		18	14·9	30	7901·0	2633 7	5·2	2·2	26·18	218·0	766·4	499
		19	15·6	50	13248·0	2649·6	5·2	1·2	25·68	215·0	765·5	502
		22	15·4	40	10564·0	2641·0	5·2	1·2	25·83	215·0	767·1	503
		24	15·2	40	10543·0	2635·8	5·2	1·2	25·68	213·0	767·1	505
		25	14.2	20	5257·5	2628·8	5·2	2·5	25·73	217·0	766·5	501
	D	25	16·3	20	5274·5	2637·2	5·2	2·6	24·82	218·0	766·9	502
B_2	D	26	14·8	30	7399·0	2466·3	5·2	2.5	26·28	214·0	765·4	501
	R	26	17·0	30	7455·0	2485·0	5·2	2·3	25·12	217·0	765·6	501
B_1	D	27	14·8	30	6832·5	2277·5	5·2	2·7	26·43	218·0	765·2	497
	R	27	17·1	40	9140·5	2285·1	5·0	2·0	25·32	214·0	765·6	503
B_3	D	28	14·7	30	7883·0	2627·7	5·1	2·5	26·48	212.0	766·6	504
		28	17·0	30	7923·0	2641·0	5·1	2·4	25·42	219·0	766·6	499
		30	14·8	30	7896·0	2632·0	[5·1]	2·4	26·03	214·0	765·0	502

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9548	—48	—470	— 8	+414	0·500 9436
	531	—50	—456	— 9	+426	442
	488	—50	—412	—15	+429	440
	484	—58	—433	— 6	+429	416
	445	—53	—399	—12	+427	408
	497	—44	—435	— 6	+427	439
	511	—31	—432	— 8	+380	420
	523	—42	—445	— 1	+375	410
	552	—50	—470	— 2	+373	403
	517	—42	—462	+ 1	+380	394
	511	—46	—464	+ 1	+395	397
	453	—31	—443	— 2	+393	370
	484	—31	—449	— 2	+385	387
	503	—31	—443	— 4	+372	397
	528	—50	—445	— 1	+357	389
D	498	—52	—408	— 2	+370	406
					June 17	410
D	0·501 0157	—50	—468	— 1	+382	0·501 0020
R	081	—47	—420	— 1	+397	010
					June 26	015
D	0·501 1001	—53	—474	+ 2	+390	0·501 0866
R	0964	—41	—428	— 2	+383	876
					June 27	871
D	0·500 9532	—49	—476	— 3	+376	0·500 9380
	484	—48	—432	+ 1	+369	374
	517	—48	—458	— 2	+377	386

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B₃	D	July 4	18·2	34	9014·0	2651·2	5·1	1·9	24·72	217·0	767·0	503
		7	17·8	30	7931·0	2643·7	5·1	2·2	25·12	214·0	767·0	505
		8	17·6	34	8945·0	2630·9	5·1	2·1	25·43	183·0	768·8	534
		17	17·2	18	4768·0	2648·9	5·1	3·0	25·33	219·0	767·2	500
		18	17·7	32	8442·0	2638·1	4·5	[1·7]	25·33	220·0	766·7	499
		22	17·6	32	8463·0	2644·7	5·0	2·0	26·03	219·0	766·6	499
		23	17·4	30	7925·0	2641·7	5·0	2·2	26·03	222·0	766·6	496
		24	17·6	30	7950·5	2650·2	5·0	2·0	25·73	222·0	766·4	496
		25	17·6	32	8475·0	2648·4	5·0	2·0	26·44	220·0	766·7	497
		26	17·6	34	9023·0	2653·8	5·0	1·8	26·13	222·0	767·0	496
		27	17·8	38	10105·5	2659·3	5·0	1·8	25·73	222·0	767·2	497
		29	17·6	30	7932·0	2644·0	5·0	2·1	26·28	222·0	766·2	494
		30	19·3	30	7913·0	2637·7	5·0	2·1	26·44	216·0	767·9	501
	D	31	18·4	34	8986·5	2643·1	4·3	1·7	26·08	218·0	766·4	500
B₂	D	Aug. 2	16·9	34	8383·0	2465·6	5·2	2·2	25·98	218·0	764·7	498
	R	2	19·2	30	7453·0	2484·3	5·1	2·2	24·72	221·0	765·1	497
B₁	D	3	16·4	44	9996·0	2271·8	5·1	2·0	26·94	218·0	765·8	497
	R	3	19·2	36	8197·0	2277·0	5·1	2·3	25·93	216·0	766·4	502
B₃	D	4	17·4	30	7887·5	2629·2	5·0	2·0	27·80	226·0	766·6	490
		5	17·5	30	7888·5	2629·5	5·0	2·1	27·45	222·0	768·0	495
		6	17·5	30	7919·5	2639·8	5·0	2·2	26·59	224·0	767·5	494
		7	17·5	30	7937·0	2645·7	5·0	2·2	26·33	221·0	766·8	496
		10	17·7	32	8469·5	2646·7	5·0	2·0	26·33	218·0	766·9	499

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9448	—40	—403	— 2	+385	0·500 9388
	474	—45	—420	— 4	+377	382
	520	—43	—433	—27	+389	406
	456	—57	—429	0	+412	382
	495	—32	—429	+ 1	+416	451
	471	—41	—458	+ 1	+400	373
	482	—44	—458	+ 3	+387	370
	451	—41	—445	+ 3	+396	364
	457	—41	—475	+ 2	+425	368
	438	—38	—462	+ 3	+435	376
	418	—38	—445	+ 2	+419	356
	473	—42	—468	+ 5	+401	369
	496	—42	—475	— 1	+390	368
D	477	—30	—460	0	+386	373
					July 17	380
D	0·501 0160	—46	—456	+ 2	+377	0·501 0037
R	0083	—45	—403	+ 2	+362	0 9999
					Aug. 2	1 0018
D	0·501 1029	—42	—496	+ 2	+362	0·501 0855
R	1004	—46	—454	— 2	+381	0883
					Aug. 3	1 0869
D	0·500 9526	—41	—531	+ 8	+391	0·500 9353
	525	—42	—517	+ 4	+403	373
	488	—44	—481	+ 5	+408	376
	467	—44	—470	+ 3	+415	371
	464	—41	—470	+ 1	+418	372

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	Aug. 11	17·5	30	7936·0	2645·3	5·0	2·0	26·59	219·0	766·6	497
		12	17·5	30	7916·0	2638·7	5·0	2·2	27·14	216·0	767·0	500
		13	17·3	30	7914·0	2638·0	5·0	2·1	27·04	215·0	767·8	501
		14	17·8	36	9523·5	2645·4	5·0	[1·9]	26·44	217·0	767·6	501
		15	17·5	30	7925·0	2641·7	5·0	2·1	26·59	219·0	766·5	497
		16	17·5	30	7933·5	2644·5	5·0	2·1	26·33	219·0	766·4	497
		20	20·3	40	10562·5	2640·6	5·0	1·7	25·53	217·0	765·1	500
		22	19·6	20	5270·0	2635·0	5·0	3·0	25·88	226·0	767·0	493
		23	20·3	40	10548·5	2637·1	5·0	[1·7]	26·03	218·0	766·0	499
		25	19·6	22	5786·5	2630·2	5·0	3·0	26·44	222·0	766·1	494
		26	19·9	30	7907·0	2635·7	5·0	2·3	26·33	220·0	766·6	496
		29	20·4	38	10031·0	2639·7	[4·8]	[1·7]	26·03	218·0	765·9	499
	D	31	19·6	20	5287·0	2643·5	5·0	3·0	25·83	224·0	765·8	494
B_2	D	Sept. 2	19·5	32	7894·5	2467·0	5·2	2·2	26·89	215·0	765·8	500
	R	2	22·3	32	7962·0	2488·1	5·2	2·2	25·47	223·0	766·0	495
B_1	D	6	19·6	32	7273·0	2272·8	5·1	[2·8]	26·64	219·0	766·5	497
	R	6	22·2	32	7289·5	2278·0	5·1	2·8	25·68	214·0	766·5	503
B_3	D	9	19·6	20	5240·5	2620·2	5·0	[3·0]	27·19	220·0	766·7	496
		12	20·4	40	10536·0	2634·0	5·0	[1·7]	26·74	215·0	765·6	501
		15	20·4	40	10540·0	2635·0	5·0	[1·7]	26·89	218·0	766·4	498
		18	19·6	20	5253·0	2626·5	5·0	3·0	27·09	219·0	766·5	496
		19	20·4	40	10562·0	2640·5	5·0	[1·7]	26·44	216·0	765·0	499
		23	21·9	42	11120·5	2647·7	5·0	1·5	25·93	216·0	765·6	501

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9468	−41	−481	+2	+420	0·500 9368
	492	−44	−504	0	+426	370
	495	−42	−500	−1	+419	371
	468	−39	−475	−1	+409	362
	481	−42	−481	+2	+405	365
	471	−42	−470	+2	+399	360
	485	−36	−437	0	+375	387
	506	−56	−452	+6	+358	362
	498	−36	−458	+1	+356	361
	523	−56	−475	+5	+357	354
	503	−45	−470	+3	+359	350
	489	−34	−458	+1	+350	348
D	475	−56	−449	+5	+379	354
					Aug. 18	364
D	0·501 0154	−46	−493	0	+377	0·500 9992
R	0068	−46	−435	+4	+375	966
					Sept. 2	979
D	0·501 1024	−54	−483	+2	+366	0·501 0855
R	0999	−54	−443	−2	+357	857
					Sept. 6	856
D	0·500 9560	−56	−506	+3	+358	0·500 9359
	509	−36	−487	−1	+362	347
	506	−36	−493	+2	+370	349
	536	−56	−502	+3	+375	356
	486	−36	−475	+1	+370	346
	460	−33	−454	−1	+377	349

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc. Initial.	Semi-arc. Final.	Temperature.	Manometer.	Barometer.	Pressure at 0° C.
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	Sept. 26	20·4	40	10598·0	2649·5	5·0	[1·7]	25·98	222·0	766·0	495
		27	21·1	40	10612·0	2653·0	5·0	[1·7]	25·43	219·0	764·5	497
		28	20·4	40	10598·0	2649·5	5·0	[1·7]	25·98	222·0	764·9	494
B_2	D	Oct. 4	23·0	30	7444·0	2481·3	5·2	2·5	24·97	224·0	765·3	495
	R	4	1·5	34	8487·0	2496·2	5·2	2·4	24·14	226·0	764·6	493
B_1	D	5	22·8	30	6871·0	2290·3	5·2	2·8	24·97	221·0	764·5	496
	R	5	1·1	36	8265·0	2295·8	5·2	2·3	24·09	223·0	764·0	496
B_3	D	8	22·6	20	5301·0	2650·5	5·0	[3·0]	24·92	222·0	765·6	496
		10	22·6	20	5265·0	2632·5	5·0	3·0	26·84	226·0	766·6	491
		14	22·6	20	5303·0	2651·5	5·0	3·0	25·12	229·0	767·2	491
		16	22·6	20	5320·0	2660·0	5·0	[3·0]	25·17	227·0	765·9	492
		22	23·2	38	10149·0	2670·8	5·0	[1·8]	24·53	222·0	765·4	497
		28	23·3	40	10671·0	2667·8	5·0	[1·7]	24·63	224·0	766·8	496
		30	23·3	40	10690·0	2672·5	5·0	[1·7]	24·04	225·0	766·5	496
B_2	D	31	22·9	32	7925·0	2476·6	5·2	2·3	25·63	225·0	767·4	494
	R	31	1·2	28	6979·0	2492·5	5·2	[2·4]	24·48	224·0	767·3	497
B_1	D	Nov. 1	22·6	34	7785·5	2289·8	5·2	2·8	25·37	238·0	766·4	482
	R	1	0·8	32	7343·5	2294·8	5·2	2·5	24·24	225·0	766·5	495

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9454	—36	—456	+ 4	+380	0·500 9346
	441	—36	—433	+ 2	+380	354
	454	—36	—456	+ 5	+378	345
					Sept. 19	350
D	0·501 0095	—50	—414	+ 4	+373	0·501 0008
R	035	—49	—379	+ 6	+373	0 9986
					Oct. 1	0 9997
D	0·501 0940	—55	—414	+ 3	+376	0·501 0850
R	913	—47	—377	+ 3	+380	872
					Oct. 5	861
D	0·500 9450	—56	—412	+ 3	+376	0·500 9361
	515	—56	—491	+ 7	+377	352
	446	—56	—420	+ 7	+379	356
	416	—56	—422	+ 6	+380	324
	378	—38	—395	+ 2	+381	328
	389	—36	—400	+ 3	+384	340
	372	—36	—375	+ 3	+384	348
					Oct. 19	344
D	0·501 0115	—47	—441	+ 5	+375	0·501 0007
R	050	—49	—393	+ 2	+370	0 9980
					Oct. 31	0 9994
D	0·501 0941	—55	—430	+14	+367	0·501 0837
R	918	—50	—383	+ 4	+367	856
					Nov. 1	846

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	Nov. 4	22·7	20	5309·5	2654·8	5·0	2·7	24·87	229·0	766·0	490
		6	23·6	38	10068·0	2649·5	[4·8]	[1·8]	25·73	223·0	766·1	495
		7	22·6	20	5274·0	2637·0	5·0	3·0	26·23	224·0	766·0	492
		8	0·3	30	7988·5	2662·8	5·0	2·1	24·33	222·0	763·2	496
		10	22·7	20	5323·0	2661·5	5·0	3·0	23·99	229·0	761·2	487
		12	22·7	20	5308·5	2654·2	5·0	3·0	24·43	226·0	764·4	492
		13	22·7	20	5292·0	2646·0	5·0	3·0	25·68	226·0	765·2	491
		14	22·7	20	5269·0	2634·5	5·0	3·0	26·68	229·0	766·4	488
		15	22·3	10	2648·5	2648·5	5·0	3·9	25·17	227·0	765·6	491
		17	0·1	40	10724·0	2681·0	5·0	[1·9]	24·43	220·0	765·0	499
		19	3·1	32	8605·0	2689·0	3·9	[1·1]	23·05	230·0	766·2	493
		21	2·0	20	5326·5	2663·2	5·0	3·0	24·43	231·0	767·0	490
		23	2·0	20	5320·0	2660·0	5·0	3·0	24·72	230·0	767·0	491
		30	1·9	20	5330·0	2665·0	5·0	3·0	24·18	226·0	767·6	496
B_2	D	Dec. 1	2·1	32	7956·0	2486·2	5·2	2·4	24·53	224·0	765·6	496
	R	1	4·9	30	7498·0	2499·3	[5·1]	2·5	23·44	226·0	765·4	495
B_1	D	5	1·9	22	5043·5	2292·5	5·2	[3·2]	25·02	225·0	767·4	495
	R	5	3·9	32	7343·0	2294·7	5·2	2·7	24·48	224·0	767·2	497
B_3	D	6	2·0	20	5312·0	2656·0	5·0	3·0	24·77	228·0	768·0	494
		7	1·9	20	5275·5	2637·8	5·0	3·0	24·67	120·0	768·8	592
		9	1·9	20	5340·0	2670·0	5·0	3·0	23·49	227·0	766·9	496
		10	1·9	20	5337·0	2668·5	5·0	3·0	23·84	228·0	764·2	491
		11	1·8	10	2703·0	2703·0	5·0	[3·9]	20·63	236·0	764·4	489

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9435	−51	−410	+ 8	+367	0·500 9349
	454	−36	−445	+ 4	+371	348
	498	−56	−446	+ 6	+363	365
	406	−42	−387	+ 3	+358	338
	411	−56	−373	+10	+358	350
	437	−56	−391	+ 6	+368	364
	466	−56	−443	+ 7	+370	344
	508	−56	−485	+ 9	+377	353
	457	−70	−422	+ 7	+384	356
	342	−39	−391	+ 1	+389	302
	314	−20	−334	+ 6	+378	344
	405	−56	−391	+ 8	+383	349
	416	−56	−403	+ 7	+379	343
	398	−56	−381	+ 3	+372	336
					Nov. 17	346
D	0·501 0075	−49	−395	+ 3	+371	0·501 0005
R	023	−49	−350	+ 4	+370	0 9998
					Dec. 1	1 0002
D	0·501 0929	−61	−416	+ 4	+373	0·501 0829
R	918	−53	−393	+ 2	+373	847
					Dec. 5	838
D	0·500 9430	−56	−405	+ 5	+378	0·500 9352
	495	−56	−401	−73	+380	345
	381	−56	−352	+ 3	+376	352
	386	−56	−367	+ 7	+368	338
	266	−70	−234	+ 9	+375	346

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1891.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	Dec. 12	1·9	20	5428·0	2714·0	5·0	[3·0]	20·00	233·0	763·6	494
		15	2·7	40	10753·0	2688·2	5·0	[1·8]	22·55	228·0	769·0	498
		17	1·9	20	5330·5	2665·2	5·0	3·0	23·84	229·0	766·8	494
		19	2·0	22	5858·0	2662·7	5·0	[2·8]	24·09	227·0	768·5	496
		21	2·7	42	11193·0	2665·0	5·0	1·8	24·53	222·0	765·8	497
		22	1·4	10	2644·0	2644·0	5·0	3·9	25·12	226·5	766·8	493
		23	1·9	20	5316·0	2658·0	5·0	3·0	24·72	231·0	769·8	492
		24	1·9	20	5327·0	2663·5	5·0	3·0	24·33	231·0	770·8	494
		25	1·9	20	5339·0	2669·5	5·0	[3·0]	23·99	231·0	771·1	495
		26	1·9	20	5347·0	2673·5	5·0	[3·0]	23·50	231·0	770·4	495
		27	1·9	20	5330·0	2665·0	5·0	3·0	24·24	231·0	768·8	492
		28	1·9	20	5326·0	2663·0	5·0	3·0	24·43	228·0	768·7	494
		29	1·9	20	5315·0	2657·5	5·0	3·0	23·99	230·5	768·3	493
		30	1·9	20	5316·0	2658·0	5·0	[3·0]	23·94	231·0	768·3	492
		1892.										
B_1	D	Jan. 1	1·6	12	2749·0	2290·8	5·2	4·0	23·70	232·0	767·3	490
B_2	D	2	1·9	22	5528·0	2512·7	5·1	3·1	21·57	234·5	767·8	493
B_3	D	5	1·9	18	4822·0	2678·9	5·0	3·1	21·77	232·0	764·7	493
	R	5	5·2	24	6461·0	2692·1	5·0	2·4	20·05	172·0	764·8	550
B_1	D	6	5·4	22	5121·0	2327·7	5·2	3·2	19·70	226·0	762·4	499
	R	6	7·3	34	7946·0	2337·1	5·2	2·2	18·42	204·0	761·8	520

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9228	—56	—208	+ 5	+368	0·500 9337
	317	—38	—313	+ 2	+368	336
	398	—56	—367	+ 5	+363	343
	407	—52	—377	+ 3	+344	325
	398	—38	—395	+ 2	+348	315
	473	—70	—420	+ 6	+363	352
	423	—56	—403	+ 6	+387	357
	404	—56	—387	+ 5	+382	348
	383	—56	—373	+ 4	+373	331
	369	—56	—353	+ 4	+384	348
	398	—56	—383	+ 6	+376	341
	406	—56	—391	+ 5	+372	336
	425	—56	—373	+ 6	+341	343
	423	—56	—371	+ 6	+338	340
					Dec. 18	341
D	0·501 0937	—75	—361	+ 8	+333	0·501 0842
D	0·500 9969	—58	—273	+ 6	+349	0·500 9993
D	0·500 9350	—57	—281	+ 6	+324	0·500 9342
R	304	—46	—210	—39	+324	333
					Jan. 5	338
D	0·501 0763	—61	—195	+ 1	+320	0·501 0828
R	720	—46	—142	—16	+320	836
					Jan. 6	832

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_2	D	Jan. 10	5·4	8	1981·0	2476·2	[5·0]	[4·2]	20·54	55·0	763·4	658
B_3	D	11	6·5	36	9722·0	2700·6	5·0	1·9	20·45	222·0	764·4	503
		12	6·3	30	8145·0	2715·0	4·5	2·0	19·90	246·0	762·8	481
B_1	D	16	5·2	18	4156·0	2308·9	5·0	3·2	22·51	229·0	762·6	491
B_2	D	18	6·4	20	5034·0	2517·0	4·8	2·9	21·23	230·0	762·6	493
	R	18	8·3	26	6574·0	2528·5	4·5	2·2	21·03	228·5	762·4	495
B_4	D	19	5·4	8	2678·8	2678·8	4·2	3·3	22·85	253·0	763.0	470
		20	6·2	30	8056·0	2685·3	4·2	2·0	22·65	227·0	765·0	496
		21	6·4	36	9612·0	2670·0	4·8	1·8	23·15	227·0	766·4	496
		23	6·4	36	9621·0	2672·5	[4·8]	[1·8]	22·95	226·0	766·2	497
		24	6·1	28	7531·0	2689·6	4·2	2·0	22·02	227·0	768·8	500
		25	6·2	30	8085·0	2695·0	4·2	[2·0]	21·92	227·0	769·8	501
		27	6·2	30	8080·0	2693·3	4·3	2·0	22·46	227·0	766·7	498
		Feb. 2	6·1	40	10720·0	2680·0	4·3	1·2	22·70	222·0	766·8	501
B_1	D	3	5·3	24	5527·0	2302·9	4·8	2·8	23·25	230·0	768·0	495
	R	3	7·0	24	5525·0	2302·3	4·8	2·8	22·85	229·0	768·0	496
B_2	D	4	5·3	22	5480·0	2490·9	4·4	2·8	23·85	226·0	767·0	497
	R	4	7·1	28	7020·5	2507·3	4·4	2·1	23·10	222·0	767·2	501

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500^mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·501 0117	−75	−230	−125	+322	0·501 0009
D	0·500 9274	−39	−226	− 2	+331	0·500 9338
	225	−35	−203	+ 15	+318	320
					Jan. 12	329
D	0·501 0851	−59	−312	+ 7	+328	0·501 0815
D	0·500 9952	−52	−258	+ 6	+336	0·500 9984
R	907	−38	−250	+ 4	+336	959
					Jan. 18	972
D	0·500 9350	−50	−326	+ 24	+351	0·500 9349
	327	−33	−317	+ 3	+326	306
	381	−36	−338	+ 3	+305	315
	372	−36	−330	+ 2	+313	321
	312	−33	−291	0	+338	326
	294	−33	−287	− 1	+373	346
	299	−34	−310	+ 2	+340	297
	346	−34	−320	− 1	+340	331
					Jan. 25	324
D	0·501 0879	−50	−342	+ 4	+319	0·501 0810
R	882	−50	−326	+ 3	+319	828
					Feb. 3	819
D	0·501 0057	−45	−367	+ 2	+344	0·500 9991
R	9991	−36	−336	− 1	+344	962
					Feb. 4	976

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	Feb. 6	6·6	40	10714·0	2678·5	4·4	1·4	23·40	227·0	766·6	495
		8	6·8	32	8587·0	2683·4	[4·0]	1·5	23·15	229·0	767·8	496
		11	5·5	12	3198·0	2665·0	4·4	3·1	23·00	233·0	766·2	490
		12	6·1	28	7504·5	2680·2	4·4	2·0	22·42	229·0	765·4	494
		13	6·1	28	7521·0	2686·1	4·4	2·0	21·59	231·0	763·6	493
		14	6·5	38	10110·0	2660·5	4·4	1·6	23·54	220·0	761·3	497
B_1	D	19	8·7	16	3704·0	2315·0	4·8	3·3	20·98	230·0	763·2	494
		20	7·0	32	7375·0	2304·7	4·8	2·2	22·31	226·0	764·5	496
		20	9·2	32	7388·5	2308·9	4·8	2·2	21·47	229·0	764·8	496
B_2	D	21	6·6	46	11431·0	2485·0	4·7	1·6	23·69	221·0	765·9	500
	R	21	9·3	26	6505·0	2501·9	4·4	2·2	22·31	227·0	766·1	497
B_3	D	22	6·4	36	9519·0	2644·2	4·4	1·7	24·92	223·0	767·6	497
		23	6·7	44	11655·5	2649·0	4·4	1·4	24·38	223·0	767·4	498
		26	8·6	10	2667·0	2667·0	4·2	3·1	23·44	229·0	767·7	494
		27	9·7	40	10717·0	2679·2	4·2	1·5	23·05	222·0	767·4	501
		28	9·4	30	8034·0	2678·0	4·2	[2·1]	23·05	227·0	768·6	498
		29	9·4	30	8044·5	2681·5	4·2	[2·1]	23·05	228·0	769·0	498
B_1	D	Mar. 1	7·6	18	4146·0	2303·3	4·7	3·0	23·40	230·0	768·0	494
	R	1	8·8	16	3687·5	2304·7	4·5	[3·1]	22·95	232·0	768·0	493

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9351	—27	—349	+4	+340	0·500 9319
	334	—25	—338	+3	+317	291
	398	—49	—332	+8	+317	342
	345	—35	—308	+5	+304	311
	325	—35	—373	+6	+298	221
	414	—29	—354	+2	+292	325
					Feb. 10	302
D	0·501 0822	—58	—248	+5	+291	0·501 0812
	871	—41	—303	+3	+291	821
	851	—41	—268	+3	+291	836
					Feb. 20	823
D	0·501 0081	—32	—361	0	+294	0·500 9982
R	012	—37	—303	+2	+294	968
					Feb. 21	975
D	0·500 9472	—31	—412	+2	+289	0·500 9320
	455	—27	—389	+2	+317	358
	392	—47	—350	+5	+338	338
	348	—27	—334	—1	+349	335
	353	—34	—334	+2	+349	336
	341	—34	—334	+2	+343	318
					Feb. 26	334
D	0·501 0878	—52	—349	+5	+333	0·501 0815
R	871	—51	—330	+6	333	829
					Mar. 1	822

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_2	D	Mar. 2	9·2	30	7512·0	2504·0	4·7	2·1	22·80	225·0	767·6	499
	R	2	11·0	16	4022·0	2513·8	4·3	3·0	22·22	230·0	767·4	495
B_3	D	4	8·8	14	3750·0	2678·6	4·2	3·0	23·30	231·0	766·5	492
		5	9·8	40	10741·0	2685·2	4·2	1·5	22·56	221·0	765·0	501
		8	11·4	16	4346·0	2716·2	4·2	2·9	19·65	236·0	764·9	492
		9	9·5	32	8748·0	2733·8	4·2	1·8	18·71	231·0	765·3	498
		10	9·4	30	8179·0	2726·3	4·2	[2·0]	19·30	230·0	765·8	500
		13	9·4	30	8087·0	2695·7	4·2	[2·0]	21·38	225·0	767·7	502
		14	9·7	38	10241·0	2695·0	4·2	1·5	21·92	222·0	767·5	503
B_1	D	16	8·3	18	4149·0	2305·0	4·2	2·9	23·30	236·0	768·0	488
	R	16	9·6	14	3229·5	2306·8	4·2	3·1	22·80	238·0	768·4	488
B_2	D	19	8·4	16	3996·0	2497·5	4·0	2·9	23·40	235·0	768·1	489
	R	19	9·5	12	3012·0	2510·0	3·9	[2·9]	22·95	237·0	768·3	489
B_3	D	20	8·9	18	4830·0	2683·3	3·2	2·0	23·15	233·0	768·8	493
		21	9·5	34	9141·0	2688·5	3·4	1·3	23·10	228·0	769·5	498
		23	10·5	30	8058·0	2686·0	3·6	[1·5]	22·85	229·0	769·3	497
		24	9·4	30	8039·0	2679·7	3·5	1·4	23·89	249·0	769·2	477
		29	9·4	30	8058·0	2686·0	3·45	1·5	23·15	225·0	769·3	500
		30	9·5	34	9106·0	2678·2	3·4	1·3	23·69	224·0	769·3	500
		31	9·4	32	8578·0	2680·6	3·4	1·5	23·59	225·0	770·0	500

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·501 0004	—39	—324	+ 1	+347	0·500 9989
R	0 9965	—47	—300	+ 4	+347	969
					Mar. 2	979
D	0·500 9351	—46	—344	+ 6	+352	0·500 9319
	327	—27	—314	— 1	+341	326
	221	—44	—193	+ 6	+343	333
	162	—30	—154	+ 2	+358	338
	186	—33	—178	0	+335	310
	291	—33	—265	— 2	+341	332
	294	—27	—287	— 2	+338	316
					Mar. 9	325
D	0·501 0870	—44	—344	+ 9	+331	0·501 0822
R	861	—47	—324	+ 9	+331	830
					Mar. 16	826
D	0·501 0030	—42	—349	+ 9	+331	0·500 9979
R	0 9980	—41	—330	+ 9	+331	949
					Mar. 19	964
D	0·500 9334	—24	—338	+ 6	+343	0·500 9321
	316	—18	—336	+ 2	+338	302
	325	—22	—326	+ 2	+334	313
	346	—20	—369	+18	+336	311
	325	—20	—338	0	+335	302
	352	—18	—361	0	+340	313
	344	—20	— 356	0	+336	304
					Mar. 26	309

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	h.		s.	s.	mm.	mm.	° C.	mm.	mm.	mm.
B_1	D	Apr. 6	11·3	18	4148·5	2304·7	5·0	3·2	22·90	231·0	768·0	494
	R	6	12·3	8	1841·0	2301·2	5·0	4·1	22·75	235·0	768·0	491
B_2	D	9	11·4	18	4465·0	2480·6	5·0	3·5	24·49	228·0	766·2	492
	R	9	13·6	42	10532·0	2507·6	5·0	2·0	23·05	224·0	765·8	498
B_3	D	13	11·6	20	5319·0	2659·5	4·5	2·9	24·28	229·0	766·5	491
		14	11·4	16	4247·0	2654·4	4·6	3·0	24·82	226·0	766·1	493
		15	11·1	12	3181·0	2650·8	4·6	3·4	24·22	228.0	766.4	492
B_1	D	16	11·3	20	4584·5	2292·2	5·0	3·1	24·77	227·0	766·8	493
	R	16	12·9	28	6434·5	2298·0	4·9	2·7	23·94	227·0	766·8	495
B_2	D	17	11·3	16	3961·0	2475·6	5·0	3·2	25·07	227·0	767·0	493
	R	17	12·3	8	1989·0	2486·2	4·9	3·1	24·53	229·0	767·0	492
B_3	D	18	12·5	26	6932·0	2666·1	4·6	2·0	24·04	225·0	767·6	496
		19	12·2	38	10129·0	2665·5	4·6	1·8	24·33	222·0	767·4	499
		20	11·5	18	4788·5	2660·3	4·6	2·8	24·77	229·0	766·8	491
		21	11·4	16	4262·0	2663·8	4·6	3·0	24·33	226·0	766·7	494
		23	11·4	16	4243·0	2651·9	4·6	3·0	25·17	226·0	765·4	492
		24	11·3	14	3724·5	2660·4	4·5	[2·9]	24·33	227·0	765·7	494
		25	11·3	14	3722·5	2658·9	4·6	3·0	24·53	227·0	766·4	493
		29	11·0	6	1590·0	2650·0	4·6	4·1	24·58	228·0	765·4	491
		May 1	12·4	32	8478·0	2649·4	4·5	[1·8]	25·63	224·0	767·0	495

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·501 0871	—59	—328	+5	+335	0·501 0824
R	888	—73	—322	+7	+335	835
					Apr. 6	830
D	0·501 0099	—63	—394	+6	+339	0·500 9987
R	0 9990	—41	—334	+2	+339	956
					Apr. 9	972
D	0·500 9418	—48	—385	+7	+340	0·500 9332
	436	—50	—408	+6	+345	329
	449	—56	—383	+6	+351	367
					Apr. 14	343
D	0·501 0930	—57	—405	+6	+343	0·501 0817
R	903	—50	—371	+4	+343	829
					Apr. 16	823
D	0·501 0119	—59	—418	+6	+345	0·500 9993
R	075	—56	—395	+6	+345	975
					Apr. 17	984
D	0·500 9395	—37	—375	+3	+337	0·500 9323
	397	—34	—387	+1	+344	321
	415	—48	—405	+7	+353	322
	403	—50	—387	+5	+347	318
	445	—50	—422	+6	+353	332
	415	—48	—387	+5	+335	320
	420	—50	—395	+6	+334	315
	452	—67	—398	+7	+340	334
	454	—33	—441	+4	+318	302
					Apr. 25	321

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_1	D	May 2	11·2	14	3186·0	2275·7	5·0	3·6	26·28	225·0	767·0	492
	R	2	12·9	26	5940·0	2284·6	4·8	2·8	24·97	221·0	766·7	498
B_2	D	4	11·4	16	3992·0	2495·0	5·0	3·3	23·20	225·0	763·8	496
	R	4	12·8	22	5518·0	2508·2	4·9	2·9	22·46	223·0	763·8	498
B_3	D	5	11·4	14	3744·0	2674·3	4·6	3·1	23·10	225·0	764·7	497
		6	11·4	14	3762·0	2687·1	4·6	3·1	22·16	227·0	764·8	496
		9	12·4	38	10164·0	2674·7	4·5	1·5	23·94	226·0	768·1	496
		10	11·5	16	4249·0	2655·6	4·6	3·1	24·68	231·0	768·0	490
		11	11·7	14	3722·0	2658·6	4·5	2·9	24·72	231·0	767·2	490
		13	13·3	26	6900·0	2653·8	4·6	2·2	25·17	231·0	768·4	490
		14	11·5	16	4222·0	2638·8	4·6	2·9	26·33	227·0	768·4	493
B_1	D	15	11·2	18	4099·0	2277·2	5·0	3·1	26·13	226·0	768·5	493
	R	15	12·8	26	5937·0	2283·5	4·9	2·8	25·17	226·0	769·0	496
B_2	D	18	11·4	16	3950·0	2468·8	4·9	3·1	25·42	225·0	766·1	494
	R	18	13·1	32	7956·0	2486·2	4·9	2·1	24·67	205·0	766·4	514
B_3	D	21	13·0	32	8478·0	2649·4	4·6	1·9	25·63	221·0	766·9	498
		22	13·0	36	9554·0	2653·9	4·6	1·9	25·32	219·0	767·9	501
		23	13·6	42	11154·0	2655·7	4·6	1·5	25·27	219·0	768·3	502
		24	14·4	20	5305·0	2652·5	4·6	3·0	24·67	224·0	770·2	499

Reduction of pendulum observations, Waikiki, Honolulu.

[Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·501 1010	—65	—468	+ 6	+328	0·501 0811
R	1 0967	—50	—414	+ 2	+328	833
					May 2	822
D	0·501 0040	—60	—340	+ 3	+342	0·500 9985
R	0 9987	—53	—310	+ 2	+342	968
					May 4	976
D	0·500 9365	—52	—336	+ 2	+340	0·500 9319
	321	—52	—297	+ 3	+353	328
	364	—29	—371	+ 3	+347	314
	432	—52	—402	+ 8	+327	313
	421	—48	—403	+ 8	+334	312
	439	—39	—422	+ 8	+343	329
	492	—49	—470	+ 6	+329	308
					May 10	318
D	0·501 1002	—57	—462	+ 6	+339	0·501 0828
R	1 0972	—51	—422	+ 3	+339	841
					May 15	834
D	0·501 0147	—56	—432	+ 5	+336	0·501 0000
R	075	—41	—401	—11	+336	0 9958
					May 18	0 9979
D	0·500 9454	—35	—441	+ 2	+346	0·500 9326
	438	—35	—428	— 1	+336	310
	432	—30	—426	— 2	+336	310
	443	—50	—401	+ 1	+340	333

Pendulum observations, Waikiki, Honolulu.

[Observer: E. D. Preston.]

Pendulum.	Position.	Date.	Epoch.	No. of coincidence intervals.	Time in seconds.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
							Initial.	Final.				
		1892.	*h.*		*s.*	*s.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_3	D	May 25	15·7	42	11175·0	2660·7	4·7	1·4	24·62	217·0	768·5	505
		26	14·4	20	5300·0	2650·0	4·7	2·9	24·92	224·0	768·9	498
		28	15·7	42	11167·0	2658·8	4·7	1·5	24·68	214·0	766·2	505
B_1	D	June 3	14·7	16	3655·0	2284·4	4·9	3·5	25·02	225·0	766·4	495
B_2	D	4	14·7	16	3953·0	2470·6	5·0	3·3	25·12	226·0	767·6	495
B_3	D	5	14·7	16	4243·0	2651·9	4·7	3·0	25·12	244·0	767·6	477
		7	14·7	16	4235·0	2646·9	4·6	3·0	25·48	227·0	767·9	493
		11	15·7	28	7421·0	2650·4	[4·4]	2·1	25·48	225·0	767·8	495

Reduction of pendulum observations, Waikiki, Honolulu.

[**Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.**]

Position.	Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
		Arc.	Temperature.	Pressure.	Rate.	
	Seconds.					*Seconds.*
D	0·500 9414	—29	—399	— 4	+333	0·500 9315
	452	—50	—412	+ 2	+333	325
	421	—31	—402	— 4	+336	320
					May 25	320
D	0·501 0968	—62	—416	+ 4	+329	0·501 0823
					June 3	0·501 0823
D	0·501 0140	—60	—420	+ 4	+334	0·500 9998
					June 4	0·500 9998
D	0·500 9445	—52	—420	+18	+339	0·500 9330
	463	—50	—435	+ 6	+342	326
	450	—36	—435	+ 4	+342	325
					June 8	327

Pendulum No. 3 was invariably swung in the direct position. No. 1 and No. 2 were used both in the direct and reverse, when possible. In order to reduce the results to the same conditions, a correction is applied when only one position was obtained. This correction is deduced from all the reversals during the year, as shown in the following table:

Differences between the periods of pendulums B_1 and B_2 for the direct and reverse positions.

Date.	B_2 D—R	B_1 D—R
1891–1892.	s.	s.
June 26	+0·000 0010	—0·000 0010
Aug. 2	+ 38	— 28
Sept. 4	+ 26	— 02
Oct. 4	+ 22	— 22
31	+ 27	— 19
Dec. 3	+ 07	— 18
Jan. 6		— 08
18	+ 25	
Feb. 3	+ 29	— 18
21	+ 14	
Mar. 1	+ 20	— 14
17	+ 30	— 08
Apr. 8	+ 31	— 11
16	+ 18	— 12
May 3	+ 17	— 22
16	+ 42	— 13
Means	+0·000 0024	—0·000 0015

The signs remain the same throughout the year, and we have a mean value of

$$\begin{aligned} & \qquad\qquad\qquad\quad s. \\ \text{for } & B_1\ (D—R) = -0{\cdot}000\ 0015 \\ & B_2\ (D—R) = +0{\cdot}000\ 0024 \end{aligned}$$

The correction, therefore, to reduce those observations made in the direct position to the mean of those made in both is

s.
+0·000 0008 for B_1 and
−0·000 0012 " B_2

These corrections being applied, we have the following table. Mean values are taken for those periods during which continuous observations were made with each pendulum:

B_1			B_2			B_3		
Date.	Period.	No. of obs.	Date.	Period.	No. of obs.	Date.	Period.	No. of obs.
1891–'92.	*Seconds.*		1891–'92.	*Seconds.*		1891–'92.	*Seconds.*	
June 27	0·501 0871	2	June 26	0·501 0015	2	June 17	0·500 9410	16
Aug. 3	869	2	Aug. 2	1 0018	2	July 14	380	17
Sept. 6	856	2	Sept. 2	0 9979	2	Aug. 17	364	18
Oct. 5	861	2	Oct. 4	0 9997	2	Sept. 19	350	9
Nov. 1	846	2	31	0 9994	2	Oct. 19	344	7
Dec. 5	838	2	Dec. 1	1 0002	2	Nov. 17	346	14
Jan. 1	850	1	Jan. 2	0 9981	1	Dec. 18	341	19
6	832	2	10	0 9997	1	Jan. 5	338	2
16	823	1	18	72	2	12	329	2
Feb. 3	819	2	Feb. 4	76	2	26	324	8
20	831	2	21	75	2	Feb. 10	302	6
Mar. 1	822	2	Mar. 2	79	2	25	334	6
16	826	2	19	64	2	Mar. 9	325	7
Apr. 6	830	2	Apr. 9	72	2	25	309	7
16	823	2	17	84	2	Apr. 14	343	3
May 2	822	2	May 4	76	2	24	321	9
15	834	2	18	79	2	May 9	318	7
June 3	831	1	June 4	86	1	24	320	7
						June 8	327	3

Comparing the preceding values with the respective mean values for each pendulum, we get the following differences. The column headed (*t*) gives the excess (minus) or defect (plus) of the observed period of the pendulum over the mean value for the year in units of the seventh decimal place of sidereal seconds. The following column, headed (*g*), gives the excess or defect of the force of gravity, the unit being one ten-millionth part of gravity. The sign plus indicates in this column that the observed force of gravity at the given date is less than the mean value for the year. The fourth column gives mean values and dates for successive groups of three:

B_1				B_2				B_3			
Mean value, 0·501 0838^{s}.				Mean value, 0·500 9986^{s}.				Mean value, 0·500 9338^{s}.			
Date.	t.	g.	Means.	Date.	t.	g.	Means.	Date.	t.	g.	Means.
1891–'92.				1891–'92.				1891–'92.			
June 27	−33	+132	Aug. 2 +109	June 26	−29	+116	July 31 +72	June 17	−72	+287	July 12 +186
Aug. 3	−31	+124		Aug. 2	−32	+128		July 14	−42	+168	
Sept. 6	−18	+ 72		Sept. 2	+ 7	− 28		Aug. 17	−26	+104	
Oct. 5	−23	+ 92	Nov. 3 +41	Oct. 4	−11	+ 44	Nov. 1 +47	Sept. 19	−12	+ 48	Oct. 19 +35
Nov. 1	−08	+ 32		31	−08	+ 32		Oct. 19	−06	+ 24	
Dec. 5	00	00		Dec. 1	−16	+ 64		Nov. 17	−08	+ 32	
Jan. 1	−12	+ 48	Jan. 8 −12	Jan. 2	+ 5	− 20	Jan. 10 −10	Dec. 18	−03	+ 12	Jan. 1 −08
6	+06	− 24		10	−11	+ 44		Jan. 5	00	00	
16	+15	− 60		18	+14	− 56		12	+09	− 36	
Feb. 3	+19	− 76	Feb. 16 −56	Feb. 4	+10	− 40	Feb. 19 −37	26	+14	− 56	Feb. 10 −72
20	+07	− 28		21	+11	− 44		Feb. 10	+36	−144	
Mar. 1	+16	− 64		Mar. 2	+07	− 28		25	+04	− 16	
16	+12	− 48	Apr. 2 −47	19	+22	− 88	Apr. 5 −51	Mar. 9	+13	− 52	Mar. 27 −49
Apr. 6	+08	− 32		Apr. 9	+14	− 56		25	+29	−116	
16	+15	− 60		17	+02	− 08		Apr. 14	−05	+ 20	
May 2	+16	− 64	May 17 −36	May 4	+10	− 40	May 19 −23	24	+17	− 68	May 16 −66
15	+04	− 16		18	+07	− 28		May 9	+20	− 80	
June 3	+07	− 28		June 4	00	00		24	+18	− 72	
								June 8	+11	− 44	

The above variations of gravity are shown graphically in illustration No. 25. The smallest square in the diagram represents one millionth part of gravity, and for this argument the plotting is done to the nearest line in the diagram. For the time argument the nearest day is plotted, four days representing the space between vertical lines.

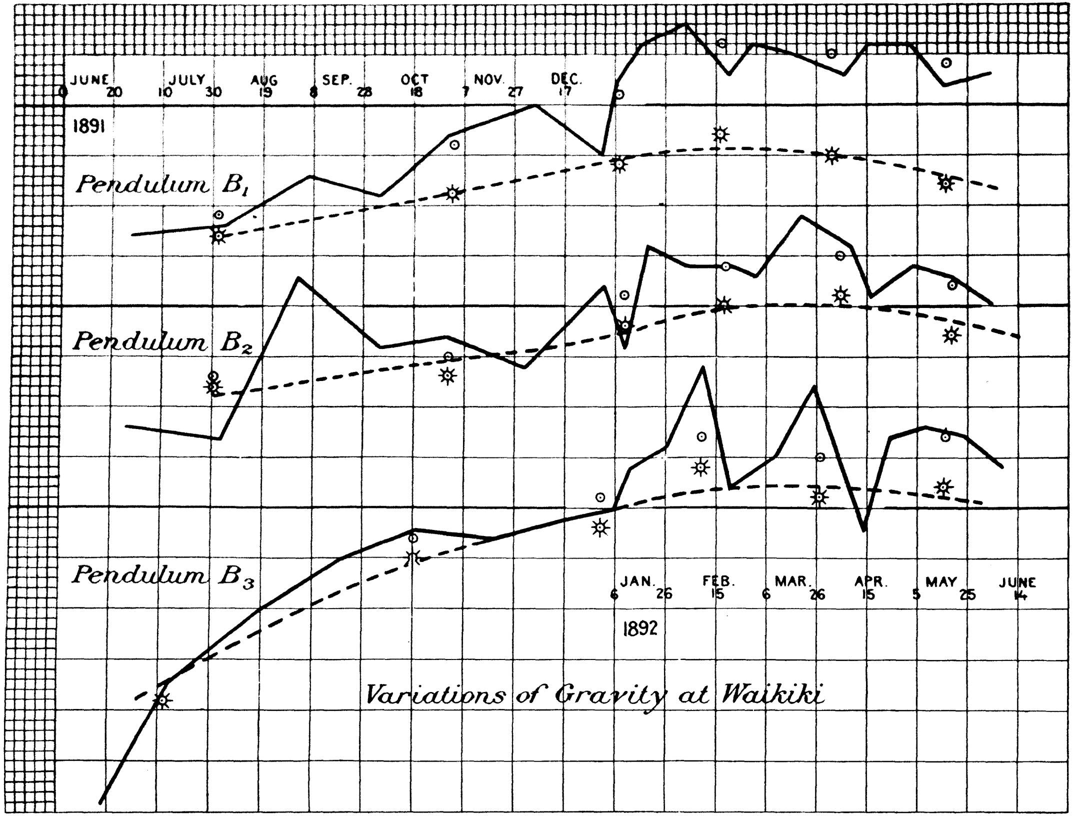
From the observations at Washington cited in the first part of this paper, it appears that the time of oscillation of the pendulums was decreased on account of use between April, 1891, and December, 1892, by the following amounts:

	s.
for B_1	0·000 0039
B_2	17
B_3	17

It is assumed that this change took place during the time the pendulums were in actual use, that is from June 9, 1891, to October 1, 1892. The above decrease in the periods correspond to an increase in the force of gravity of

15·6 millionths of g for pendulum B_1
6·8 " " " " " B_2
6·8 " " " " " B_3

Supposing that this effect was proportional to the time, we have the following table, which gives the apparent increase in gravity after cor-



Variations of Gravity at Waikiki

recting for wear of the knives. These values are plotted in illustration No. 25 and are indicated by the sign ☼:

Pendulum.	Date.	dg.	Days from June 9, 1891.	Effect of wear.	Apparent increase of g.
	1891–'92.				
B_1	Aug. 2	+109	54	+ 17	+126
	Nov. 3	+ 41	147	+ 48	+ 89
	Jan. 8	− 12	213	+ 69	+ 57
	Feb. 18	− 56	254	+ 83	+ 27
	Apr. 2	− 47	298	+ 97	+ 50
	May 17	− 36	343	+111	+ 75
B_2	July 31	+ 72	52	+ 7	+ 79
	Nov. 1	+ 47	145	+ 21	+ 68
	Jan. 10	− 10	215	+ 31	+ 21
	Feb. 19	− 37	255	+ 36	− 1
	Apr. 5	− 51	301	+ 43	− 8
	May 19	− 23	345	+ 49	+ 26
B_3	July 12	+186	33	+ 5	+191
	Oct. 19	+ 35	132	+ 19	+ 54
	Jan. 1	− 8	206	+ 29	+ 21
	Feb. 10	− 72	246	+ 35	− 37
	Mar. 27	− 49	292	+ 41	− 8
	May 16	− 66	342	+ 49	− 17

After thus correcting for wear we then have an increase of gravity, between July, 1891, and May, 1892, of

5 millionths for B_1
5 " " B_2
21 " " B_3

giving an average of 10 millionths for the three pendulums. This is equivalent to a decrease of $\frac{1}{400\,000}$ of a second in the time of oscillation of a half-second pendulum. When we consider that all three pendulums indicate a slight increase of the force of gravity, it is worth while to examine the conditions under which the work was done. The influences bearing on the result were in several respects such that their effect on differences of the force of gravity would be entirely eliminated when comparisons are made between observations made one year apart. Any effect on the time of oscillation of the pendulum depending on the influence of climate should be the same at the same season of the year. The influence of temperature on the rate of the chronometer and the effect of erroneous indications of the thermometer consequent upon the failure of the pendulums to take the temperature as soon as the mercury in the thermometer, although varying with the season, should be nearly the same for June, 1891, and June, 1892. These conditions, moreover, change but little throughout the year at Waikiki. The star places can not affect the character of the result, since the same stars were observed for time during several months, and the identical ones were used for the work of June, 1891, and in the determinations twelve months later. It is true that the wear of the knives was perceptible during the year, and that this effect on the time of oscillation of the pendulums is the same as would be produced by an increase of the force of gravity. But the effect of wear will not quite account for the observed decrease in the period of the pendulums. In fact, the observed decrease in B_3 is more than three times that attributed to wear. Moreover, we must not lose sight of the fact that this effect was determined by a comparison of the times of oscillation at Washington before and after the work at Waikiki, and that this naturally assumes that the force of gravity at Washington was constant during the year, or at least that it was the same at the time that the two determinations were made. This may or may not be the case. Indeed, there is, a priori, no more reason to suppose a variation at one place than at the other, except the volcanic nature of the islands, and the effect of wear would probably best be estimated by considering alone the Waikiki observations in which one of the pendulums was swung so much more than the other two that the effect of wear on these may be neglected in the comparison. Pendulum No. 1 and pendulum No. 2 were each used on 18 nights, while pendulum No. 3 was used on 163 nights, or in the proportion of about 9 to 1. The weight of all the pendulums being the same, the agate knives being of the same material, and the support being identical, we should expect equal effects for equal amounts of work, and a tolerable accurate estimate of the effect of use may be had independent of the Washington comparisons. It is well known that the effect on the time of oscillation of the wearing off of the knife and of its blunting are in opposite directions. In the first case the pendulum is virtually made longer and hence oscillates slower. In the latter the effect is to make it oscillate more rapidly, so that there is some compensation in the total effect. Whatever may have been the effect of use, as regards the amount to be attributed to each of these causes, the pendulums do not seem to have diverged from each other more than a few millionths of a second during the year, and there appear no progressive changes depending on the time, which should be the case if these changes were a function of the wear. The following table gives a comparison of the pendulums at those times during the year when a change was made from one instrument to the other. Since B_1 and B_2 were swung between the times of swinging B_3, the mean value of B_3 before and after is compared with each of the others. The unit is one ten-millionth of a sidereal second.

Comparison of pendulums.

[The unit is in the seventh decimal place of a sidereal second.]

Date.	B_3			B_2 Mean D and R.	B_1 Mean D and R.	$B_1—B_3$	$B_2—B_3$	$B_2—B_3$
	Before.	After.	Mean.					
1891–'92.								
June 26	9398	9377	9388	10015	10871	856	1483	627
Aug. 2	70	63	66	18	69	851	1503	652
Sept. 4	51	53	52	9979	56	877	1504	627
Oct. 4	50	56	53	97	61	864	1508	644
31	44	48	46	94	46	852	1500	648
Dec. 3	40	48	44	10002	38	836	1494	658
Jan. 2	42	38	40	9981	50	869	1510	641
10	38	29	34	97	32	835	1498	663
18	29	28	28	72	23	851	1495	644
Feb. 3	14	05.	10	76	19	843	1509	666
20	25	39	32	75	31	856	1499	643
Mar. 1	27	22	24	79	22	843	1498	655
16	24	12	18	64	26	862	1508	646
Apr. 9	08	30	19	72	30	858	1511	653
16	48	22	35	84	23	839	1488	649
May 2	18	24	21	76	22	846	1501	655
18	18	18	18	79	34	855	1516	661
June 4	22	28	25	86	31	845	1506	661
						Means	1502	650

Differences from mean value.

Date.	$B_1—B_3$	$B_2—B_3$	Date.	$B_1—B_3$	$B_2—B_3$	Date.	$B_1—B_2$	$B_2—B_3$
1891.			1892.			1892.		
June 26	+19	+23	Jan. 2	— 8	+ 9	Mar. 16	— 6	+ 4
Aug. 2	— 1	— 2	10	+ 4	—13	Apr. 9	— 9	— 3
Sept. 4	— 2	+23	18	+ 7	+ 6	16	+14	+ 1
Oct. 4	— 6	+ 6	Feb. 3	— 7	—16	May 2	+ 1	— 5
31	+ 2	+ 2	20	+ 3	+ 7	18	—14	—11
Dec. 3	+ 8	— 8	Mar. 1	+ 4	— 5	June 4	— 4	—11

The fact that the pendulums were not swung at the same station in Washington before and after the work in the Hawaiian Islands can hardly throw any uncertainty on the comparisons before and after the expedition. The connection was made by the telegraphic method, the pendulums being swung simultaneously and the greatest discrepancy of the period of individual swings from the mean value was only one part in two and one-half millions. It does not seem that the corrections for amplitude, temperature, atmospheric pressure, or rate of chronometer could be in error sufficiently to account for the change of gravity noticed at Waikiki. Even supposing that the coefficients were not strictly accurate, or that the amplitude scale was not true this would not influence relative gravity, since the corrections were calculated with the same constants throughout. The rate of the chronometer was determined each night from star observations and also from observations before and after the gravity determinations, in order to detect any irregularity in the rate during the interval from night to night. The result of this investigation was that greater irregularities were found in the corrections for rate, but it is doubtful whether these variations were really in the movement of the chronometer or whether the period of two or three hours was not so short that they came from uncertainties in the corrections themselves. Under either supposition, however, the result for the variation of gravity for the year is unchanged, because when we apply these corrections, deduced from determinations before and after the pendulum work, we get practically the same result for the periods of continuous work with each pendulum. For example, for those periods when B_3 was swung continuously we have the following differences in the rate corrections by the two methods:

			s.
Oct. 5	to	Oct. 30	+0·000 0007
Nov. 4		Nov. 30	+ 05
Dec. 9		Dec. 30	— 01
Jan. 20		Jan. 27	+ 11
Feb. 6		Feb. 14	— 08
23		29	+ 06
Mar. 5		Mar. 19	— 08
21		31	+ 07
Apr. 19		May 1	— 10
May 5		14	+ 12
21		28	— 08
		Mean =	+0·000 0001

It appears, then, that we can not explain the progressive change in period during the year by using clock corrections computed from short intervals extending over the pendulum work for each night, and that on the average the corrections for short intervals do not differ materially from those adopted from the daily rates.

It is now worth while to see what a change of $\frac{1}{400\,000}$ of a second in the period of the pendulums represents in the determination of the period and in the corrections that are applied to it. In order to have a convenient standard of reference, this effect was calculated for one-millionth of a second, and we have approximately—

A change of 0·000001^{s} in the deduced period is produced by an error
of 5 seconds in noting the coincidence between the chronometer and pendulum (swing one hour long);
of ½ mm. in estimating both initial and final arcs (swing from half amplitude, 5·0 mm. to 3·0 mm.);
of 0°·25 C. in noting the temperature of the pendulum;
of 12 mm. in noting height of manometer;
of 0·2^{s} per day in the rate of the chronometer.

An error of $\frac{1}{400\,000}$ of a second in the pendulum period would imply magnitudes at least twice those given above.

HIGH AND LOW WATER AT HONOLULU, HAWAIIAN ISLANDS, FROM JUNE 17, 1891, TO JUNE 30, 1892.

VARIATION OF THE SEA LEVEL.

In connection with the variations of gravity, if such variations really exist, it may not be out of place to show the variations of the sea level.

No ordinary movement of the tides, however, can sensibly affect our results, as has been shown both theoretically and practically by several eminent authorities. (See Helmert Theil, II, pp. 144, 155; Thomson and Tait, Vol. I, Part II; Woodward Bulletin No. 48, U. S. Geological Survey, etc.)

Professor Woodward's equation is

$$\frac{dg}{g}=\frac{3}{2}\frac{h}{r}\frac{\delta}{\triangle}\int_{0}^{\theta_1}\varphi(\theta)\cos\tfrac{1}{2}\theta\,d\theta$$

where $g =$ acceleration of gravity.
$\delta =$ density of superposed mass.
$\triangle =$ mean density of earth.
$r =$ radius of earth.
$h\,\varphi(\theta) =$ thickness of superposed lenticular mass at angular distance θ from center of mass $[h\,\varphi(\theta) = h_1$ for $\theta = 0]$.
$\theta_1 =$ limiting angle of θ.

If we take $\varphi(\theta) = \cos 2$ and $\theta_1 = 60^\circ$ we have

$$\frac{dg}{g}=\frac{3}{2}\frac{h}{r}\frac{\delta}{\triangle}\int_{0}^{60^\circ}\cos 2\theta\cos\tfrac{1}{2}\theta\,d\theta$$

If $\frac{\delta}{\triangle}$ is taken equal to $\frac{1}{6}$ the above equation gives

$$\frac{dg}{g}=\frac{1}{10}\frac{h}{r}\text{ approximately}$$

which shows that a wave of the above form must be 21 feet high in order to change gravity by its ten-millionth part.

The following table gives the times of high and low water at Honolulu, together with the reduced height. The local mean civil time is given, the hours counting from midnight. Interpolated values are given in brackets. The heights refer to the mean sea level for the period between June 17, 1891, and June 30, 1892. This mean sea level is derived from all the staff readings for the period under consideration. The table has been furnished by the Tidal Division in the Coast and Geodetic Survey Office from records sent by the Hawaiian Government Survey. Mr. C. J. Lyons, in charge of the Government Survey Office at Honolulu, has called attention to the existence of a relation between the variations of latitude and the change in the sea level.

High and low water, Honolulu, Hawaiian Islands.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected. time.	Reduced height.	Corrected time.	Reduced height.
1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
June 17			5 45	—1·00	July 12	9 45	—0·05	1 45	—0·85
	13 30	+0·60	19 30	—0·50		19 50	+0·30	12 30	—0·25
18	0 10	—0·15	5 55	—1·10	13	10 00	+0·15	3 55	—0·75
	13 30	+0·85	20 40	—0·55		19 30	+0·20	15 20	—0·10
19	0 30	—0·20	6 30	—1·00	14	11 20	+0·55	3 00	—0.75
	14 10	+1·15	21 15	—0·60		21 40	+0·20	16 50	—0·10
20	0 50	—0·40	7 30	—1·20	15	11 30	+0·80	[3 40]	[—0·75]
	15 00	+1·20	22 30	—0·80		[22 45]	[+0·05]	[18 50]	[—0·20]
21	2 30	—0·50	8 15	—1·25	16	13 00	+1·00	[4 20]	[—0.70]
	15 30	+1·30	23 00	—0·85		23 50	0·00	20 50	—0·30
22	2 45	—0·55	8 30	—1·20	17	-----	------	5 00	—0·70
	16 30	+1·25	-----	------		[13 30]	[+1·25]	[21 30]	[—0·35]
23	4 20	—0·65	0 30	—1·10	18	[0 45]	[0·00]	[6 35]	[—0·65]
	17 15	+1·20	9 45	—1·35		[14 00]	[+1·45]	[22 00]	[—0·40]
24	5 20	—0·55	0 30	—1·10	19	[1 35]	[0·00]	[7 20]	[—0·75]
	17 55	+1·15	9 35	—1·30		14 30	+1·65	22 30	—0·45
25	6 25	—0·55	1 30	—1·15	20	2 25	0·00	8 00	—0·85
	[18 35]	[+1·05]	[10 35]	[—1·00]		15 00	+1·70	23 00	—0·50
26	[7 30]	[—0·35]	[1 55]	[—1·20]	21	3 30	0·00	8 30	—0·85
	19 20	+0·95	11 30	—0·85		15 45	+1·70	23 35	—0·50
27	[8 30]	[—0·05]	2 20	—1·20	22	4 20	0·00	9 20	—0·90
	20 30	+0·70	12 30	—0·70		16 30	+1·50	-----	------
28	9 30	+0·20	3 20	—1·25	23	5 10	—0·05	0·15	—0·55
	21 40	+0·45	15 10	—0·45		17 45	+1·40	10·10	—0·80
29	10 50	+0·45	4 15	—1·20	24	6 15	+0·10	0·15	—0·70
	22 00	+0·30	17 10	—0·30		18 15	+1·25	10·45	—0·60
30	12 30	+0·75	4 45	—1·10	25	6 40	+0·20	1·10	—0·70
	22 55	+0·05	17 50	—0·30		18 45	+1·00	10 45	—0·40
July 1	12 45	+1·00	5 10	—1·10	26	8 00	+0·30	2 10	—0·75
	23 30	—0·15	20 30	—0·50		19 30	+0·70	12 30	—0·10
2	13 45	+1·20	6 30	—1·15	27	9 30	+0·50	2 30	—0·75
	-----	------	20 45	—0·65		20 00	+0·40	15 35	0·00
3	1 15	—0·30	6 40	—1·20	28	11 30	+0·75	3 00	—0·75
	14 15	+1·10	21 30	—0·95		21 00	+0·10	16 45	—0·05
4	2 00	—0·50	[7 20]	[—1·20]	29	12 20	+1·10	4 10	—0·70
	14 50	+1·35	22 45	—0·75		22 30	—0·10	19 30	—0·10
5	2 50	—0·40	8 00	—1·15	30	12 45	+1·30	4 10	—0·65
	15 35	+1·30	23 00	—0·70		23 40	—0·15	21 00	—0·30
6	3 30	—0·40	8 30	—1·15	31	-----	------	5 30	—0·70
	16 00	+1·25	-----	------		13 25	+1·30	21 20	—0·40
7	4 20	—0·35	0 20	—0·65	Aug. 1	2 15	—0·20	6 00	—0·65
	16 30	+1·40	9 15	—1·00		14 10	+1·45	[21 45]	[—0·45]
8	5 00	—0·15	0 00	—0·75	2	[2 25]	[—0·25]	[6 40]	[—0·65]
	17 20	+1·10	9 30	—0·95		[14 30]	[+1·40]	[22 05]	[—0·50]
9	6 15	—0·30	0 45	—0·65	3	[3 00]	[—0·20]	[7 20]	[—0·60]
	18 20	+1·00	10 50	—0·75		[14 55]	[+1·35]	[22 30]	[—0·55]
10	6 30	—0·20	1 50	—0·65	4	[3 35]	[—0·15]	[8 00]	[—0·55]
	18 30	+0·75	11 30	—0·75		[15 20]	[+1·25]	[22 25]	[—0·55]
11	8 00	—0·15	2 00	—0·85	5	[4 00]	[—0·15]	8 45	—0·50
	19 50	+1·10	11 00	—0·50		15 45	+1·15	23 20	—0·60

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Aug 6	4 15	—0·10	9 30	—0·65	Aug. 31	2 15	+0·40	6 45	—0·30
	16 40	+1·00	-----	------		15 00	+1·70	21 40	—0·15
7	5 30	—0·05	0 30	—0·60	1	2 40	+0·55	7 50	—0·45
	17 15	+0·75	9 45	—0·55		15 10	+1·70	22 10	—0·15
8	[6 00]	[+0·05]	0 35	—0·55	2	3 10	+0·60	8 30	—0·40
	17 30	+0·80	10 30	—0·25		15 50	+1·50	22 30	—0·20
9	6 45	+0·20	1 00	—0·45	3	3 45	+0·70	9 00	—0·40
	18 00	+1·00	11 50	—0·20		16 10	+1·60	22 50	—0·25
10	9 50	+0·30	1 50	—0·50	4	4 25	+1·00	9 30	—0·30
	18 00	+0·40	13 10	0·00		16 20	+1·30	22 50	—0·40
11	9 30	+0·45	1 40	—0·50	5	4 30	+0·90	10 30	—0·35
	19 45	+0·20	14 20	+0·15		17 10	+1·05	23 30	—0·55
12	11 00	+0·60	1 45	—0·50	6	5 30	+0·80	11 15	—0·15
	19 00	+0·10	17 50	0·00		17 30	+0·95	-----	------
13	11 30	+0·85	3 00	—0·60	7	6 30	+1·00	0 10	—0·40
	22 30	—0·10	18 15	—0·05		17 50	+0·80	12 30	+0·10
14	12 30	+1·15	4 20	—0·60	8	6 40	+1·10	0 30	—0·30
	23 20	—0·10	21 15	—0·30		17 45	+0·55	12 30	+0·10
15	-----	------	4 40	—0·65	9	7 00	+1·05	0 00	—0·40
	13 10	+1·30	21 00	—0·40		18 00	+0·40	15 00	+0·15
16	1 00	—0·20	5 50	—0·75	10	8 20	+1·15	1 30	—0·35
	14 10	+1·45	21 30	—0·50		19 50	+0·40	16 30	+0·20
17	2 20	—0·10	7 00	—0·75	11	10 00	+1·30	2 30	—0·30
	14 30	+1·65	21 20	—0·50		20 30	+0·10	17 50	+0·05
18	2 30	0·00	7 40	—0·70	12	11 30	+1·35	3 00	—0·30
	15 00	+1·80	22 00	—0·45		23 00	+0·10	19 00	—0·05
19	3 15	+0·30	8 30	—0·80	13	-----	------	4 30	—0·30
	15 40	+1·75	23 05	—0·50		12 30	+1·60	20 30	—0·10
20	4 20	+0·45	9 30	—0·65	14	0 40	+1·20	5 10	—0·30
	16 30	+1·75	23 30	—0·55		13 20	+1·60	20 40	—0·35
21	4 35	+0·60	10 20	—0·50	15	2 20	+0·40	6 35	—0·45
	17 10	+1·40	23 45	—0·60		14 10	+1·80	21 30	—0·45
22	6 00	+0·75	11 10	—0·25	16	2 30	+0·45	8 00	—0·50
	17 30	+1·25	-----	------		[15 00]	[+1·70]	[22 00]	[—0·50]
23	6 40	+1·00	0 20	—0·55	17	3 15	+0·70	9 10	—0·50
	[18 15]	[+1·05]	[12 20]	[0·00]		15 50	+1·60	22 30	—0·55
24	[7 35]	[+1·10]	[0 55]	[—0·50]	18	3 55	+0·95	9 20	—0·35
	19 00	+0·85	13 35	+0·30		16 30	+1·45	22 30	—0·70
25	8 30	+1·25	1 30	—0·40	19	4 40	+1·30	10 40	—0·30
	19 30	+0·50	16 00	+0·25		16 50	+1·35	23 10	—0·60
26	10 15	+1·40	2 30	—0·45	20	5 30	+1·40	11 40	—0·15
	20 45	+0·40	17 30	+0·25		17 30	+1·05	23 20	—0·50
27	11 40	+1·45	3 10	—0·35	21	6 30	+1·55	-----	------
	21 30	+0·20	18 50	+0·05		17 50	+0·80	12 45	+0·20
28	12 00	+1·50	4 15	—0·30	22	7 30	+1·55	0 00	—0·30
	-----	------	20 20	—0·10		17 30	+0·45	15 00	+0·10
29	0 10	+0·20	4 30	—0·40	23	9 00	+1·50	0 50	—0·35
	13 20	+1·65	20 30	—0·10		20 20	+0·20	16 30	+0·15
30	1 30	+0·35	5 45	—0·35	24	10 00	+1·50	1 35	—0·20
	14 05	+1·65	21 30	—0·10		22 00	+0·15	18 00	—0·10

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced. height.		Corrected time.	Reduced height.	Corrected. time.	Reduced height.
1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Sept. 25	10 30	+1·30	2 45	—0·10	Oct. 20	5 30	+1·45	12 05	—0·20
	-----	------	18 40	—0·20		16 50	+0·10	22 55	—0·70
26	0 10	+0·20	4 10	—0·20	21	6 45	+1·45	14 00	—0·25
	11 50	+1·40	20 30	—0·10		18 10	—0·05	23 30	—0·30
27	0 45	+0·45	5 45	—0·20	22	7 30	+1·30	16 30	—0·20
	12 30	+1·40	20 30	—0·25		22 30	—0·10	-----	------
28	1 50	+0·45	6 45	—0·30	23	8 25	+1·30	0 15	—0·25
	13 20	+1·45	20 30	—0·35		23 50	—0·05	17 30	—0·25
29	1 50	+0·55	7 10	—0·30	24	9 45	+1·10	1 30	—0·15
	14 00	+1·40	21 00	—0·50		-----	------	18 30	—0·35
30	2 15	+0·65	8 15	—0·50	25	0 30	+0·15	3 00	0·00
	14 30	+1·30	21 00	—0·50		12 00	+1·05	18 45	—0·40
Oct. 1	2 45	+0·80	8 50	—0·45	26	1 10	+0·30	5 00	0·00
	15 05	+1·20	21 20	—0·65		12 10	+1·00	18 50	—0·50
2	3 30	+0·95	9 10	—0·50	27	1 50	+0·50	6 20	—0·10
	15 10	+1·05	21 45	—0·60		12 45	+0·90	19 15	—0·70
3	3 45	+1·15	10 00	—0·40	28	2 00	+0·65	7 00	—0·30
	15 45	+0·90	22 00	—0·55		13 20	+0·80	20 00	—0·70
4	4 30	+1·30	10 50	—0·30	29	2 40	+0·70	7 30	—0·30
	16 15	+0·90	22 30	—0·55		13 20	+0·60	20 00	—0·75
5	5 00	+1·35	11 40	—0·25	30	2 35	+0·90	[8 15]	[—0·30]
	16 40	+0·80	23 00	—0·50		[14 05]	[+0·60]	[20 25]	[—0·70]
6	5 40	+1·40	12 30	—0·10	31	[3 05]	[+1·15]	9 00	—0·30
	17 20	+0·65	23 20	—0·50		14 50	+0·60	20 50	—0·70
7	6 30	+1·30	-----	------	Nov. 1	3 30	+1·40	9 40	—0·50
	18 20	+0·30	14 15	0·00		15 00	+0·45	21 00	—0·70
8	7 10	+1·35	0 00	—0·45	2	4 00	+1·40	11 00	—0·25
	18 45	+0·05	15 00	—0·20		16 30	+0·30	21 00	—0·60
9	8 30	+1·20	0 10	—0·40	3	4 20	+1·40	12 30	—0·10
	20 30	—0·05	16 30	—0·15		16 15	+0·30	21 40	—0·70
10	10 00	+1·20	1 00	—0·30	4	5 30	+1·50	12 50	—0·10
	23 00	—0·05	17 50	—0·45		16 40	+0·10	21 50	—0·55
11	10 30	+1·35	3 20	—0·30	5	6 10	+1·40	14 30	—0·10
	-----	------	18 30	—0·50		17 30	+0·10	21 30	—0·50
12	0 45	+0·10	4 45	—0·30	6	7 00	+1·45	16 40	—0·20
	11 50	+1·35	19 30	—0·70		19 15	—0·10	22 20	—0·30
13	0 20	+0·25	6 20	—0·45	7	8 00	+1·30	17 00	—0·30
	12 35	+1·45	19 45	—0·75		19 30	—0·15	22 40	—0·25
14	1 30	+0·60	7 10	—0·50	8	9 30	+1·20	-----	------
	13 20	+1·30	20 30	—0·75		22 45	—0·10	17 30	—0·45
15	2 00	+0·75	8 30	—0·45	9	11 00	+1·40	2 45	—0·15
	14 05	+1·25	21 00	—0·80		-----	------	18 00	—0·25
16	3 10	+1·00	8 45	—0·55	10	0 00	+0·30	3 10	+0·10
	14 50	+1·20	21 20	—0·85		10 30	+1·30	18 30	—0·30
17	3 45	+1·30	10 10	—0·45	11	0 30	+0·50	5 30	+0·05
	15 20	+0·85	21 50	—0·95		11 50	+1·10	18 50	—0·55
18	[4 10]	[+1·40]	11 00	—0·50	12	2 00	+0·90	7 10	—0·15
	16 15	+0·50	22 00	—0·90		12 00	+0·90	19 15	—0·60
19	4 35	+1·55	11 55	—0·35	13	1 30	+1·15	8 00	—0·20
	16 40	+0·20	22 30	—0·75		13 00	+0·70	20 00	—0·65

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1891.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Nov. 14	2 45	+1·30	9 10	—0·20	Dec. 9	10 00	+1·00	4 10	—0·05
	13 30	+0·40	20 00	—0·90		-----	------	17 20	—0·60
15	3 50	+1·60	10 45	—0·30	10	0 30	+0·75	6 00	+0·15
	15 30	+0·30	21 15	—0·90		11 20	+0·70	18 00	—0·70
16	3 50	+1·60	11 30	—0·35	11	1 45	+1·20	7 00	0·00
	16 20	+0·05	21 00	—1·00		11 30	+0·55	18 50	—0·75
17	5 50	+1·65	12 40	—0·40	12	1 50	+1·45	8 00	—0·15
	17 00	0·00	21 15	—0·65		[12 35]	[+0·35]	[19 25]	[—0·85]
18	6 10	+1·70	13 45	—0·50	13	[2 30]	[+1·50]	[9 20]	[—0·35]
	17 10	—0·15	22 00	—0·65		[13 40]	[+0·10]	[19 55]	[—1·00]
19	6 45	+1·40	14 25	—0·40	14	[3 10]	[+1·60]	10 40	—0·55
	18 30	—0·20	23 20	—0·55		14 50	—0·10	20 30	—1·10
20	7 20	+1·25	15 55	—0·45	15	3 50	+1·65	11 20	—0·55
	20 10	—0·10	23 50	—0·30		15 50	—0·05	20 50	—1·00
21	8 00	+1·25	15 45	—0·45	16	4 30	+1·75	12 15	—0·60
	20 45	—0·05	23 10	—0·20		15 45	—0·05	21 25	—1·00
22	8 45	+1·20	-----	------	17	5 15	+1·60	12 30	—0·60
	23 45	+0·05	16 40	—0·50		17 20	—0·05	22 20	—0·90
23	9 50	+1·00	3 00	0·00	18	5 30	+1·60	13 10	—0·60
	-----	------	17 10	—0·40		17 30	0·00	22 50	—0·85
24	0 00	+0·25	5 00	+0·05	19	6 30	+1·40	13 45	—0·55
	11 00	+0·80	17 45	—0·45		18 30	—0·10	23 00	—0·50
25	1 00	+0·50	5 30	+0·05	20	7 30	+1·10	14 20	—0·70
	11 30	+0·70	18 00	—0·40		[19 45]	[+0·05]	[23 45]	[—0·35]
26	1 20	+0·80	7 00	+0·05	21	[8 00]	[+0·95]	-----	------
	11 20	+0·60	18 30	—0·50		20 55	+0·20	14 55	—0·55
27	1 50	+1·00	7 45	—0·10	22	8 30	+0·80	0 30	—0·20
	12 15	+0·60	19 00	—0·40		22 40	+0·30	16 00	—0·65
28	2 35	+1·25	8 30	—0·05	23	9 00	+0·45	3 50	0·00
	13 30	+0·30	19 45	—0·55		-----	------	17 00	—0·70
29	3 00	+1·30	9 10	—0·30	24	1 00	+0·25	5 30	—0·10
	14 00	+0·05	20 15	—0·80		9 30	+0·30	17 45	—0·80
30	4 05	+1·30	10 30	—0·30	25	1 15	+0·80	6 30	—0·10
	15 20	+0·15	20 30	—0·65		11 10	+0·15	18 00	—0·95
Dec. 1	3 50	+1·50	11 20	—0·35	26	1 40	+0·90	7 40	—0·35
	15 20	+0·10	21 00	—0·60		12 15	+0·10	18 30	—1·05
2	5 10	+1.70	12 15	—0·35	27	1 50	+1·15	[8 45]	[—0·40]
	15 50	+0·05	21 30	—0·75		[13 15]	[—0·05]	[18 55]	[—1·10]
3	5 15	+1·60	12 45	—0·45	28	2 45	+0·85	9 45	—0·50
	17 00	0·00	22 15	—0·80		14 15	—0·15	19 20	—1·10
4	5 50	+1·55	14 20	—0·45	29	3 10	+1·40	10 40	—0·65
	17 40	—0·20	22 30	—0·65		14 50	—0·25	20 30	—1·00
5	7 00	+1·50	14 40	—0·55	30	[3 45]	[+1·50]	[11 15]	[—0·45]
	18 30	—0·05	23 00	—0·50		[15 30]	[+0·05]	21 00	—0·15
6	8 00	+1·40	-----	------	31	4 25	+1·55	11 50	—0·25
	19 50	+0·05	14 30	—0·60		16 15	+0·35	21 30	—0·50
7	8 30	+1·30	0 50	—0·35	1892.				
	20 40	+0·20	15 30	—0·50	Jan. 1	5 15	+2·10	12 30	—0·90
8	8 30	+1·20	2 20	—0·10		16 30	—0·30	22 10	—1·15
	23 30	+0·35	16 40	—0·60	2	5 50	+1·40	13 00	—0·85
						17 50	—0·25	22 40	—1·00

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Jan. 3	6 30	+1·20	13 50	—1·00	Jan. 28	3 30	+1·35	11 00	—0·75
	18 45	—0·20	23 40	—0·80		15 40	—0·25	20 45	—1·15
4	7 00	+1·00	14 00	—0·90	29	4 30	+1·50	11 30	—0·80
	20 00	—0·10	-----	------		16 15	—0·20	21 30	—1·30
5	7 50	+0·80	0 10	—0·50	30	4 30	+1·40	11 35	—0·80
	21 30	+0·10	15 10	—0·80		16 50	+0·10	22 00	—0·95
6	8 30	+0·65	2 15	—0·15	31	5 10	+1·40	12 30	—0·85
	23 20	+0·60	15 50	—0·75		17 50	+0·10	23 00	—0·85
7	8 30	+0·55	4 30	+0·10	Feb. 1	5 50	+1·30	12 55	—0·80
	-----	------	16 00	—0·65		18 30	+0·25	23 30	—0·75
8	0 20	+1·00	6 50	0·00	2	6 40	+1·00	13 20	—0·85
	10 00	+0·30	16 30	—0·70		19 30	+0·50	-----	------
9	0 30	+1·35	8 15	—0·05	3	7 15	+0·60	0 30	—0·30
	11 20	+0·05	17 20	—0·90		20 30	+0·60	13 30	—0·90
10	1 30	+1·35	9 45	—0·40	4	7 50	+0·35	2 00	0·00
	12 15	—0·15	18 40	—0·95		22 00	+0·65	14 10	—0·85
11	2 10	+1·40	10 00	—0·65	5	9 30	0·00	6 10	—0·05
	14 15	—0·30	18 40	—1·05		23 30	+0·85	15 00	—0·70
12	2 55	+1·50	11 30	—0·70	6	9 00	—0·15	7 00	—0·10
	15 00	—0·25	20 00	—1·05		-----	------	15 30	—0·75
13	3 45	+1·70	11 00	—0·50	7	0 20	+1·00	8 30	—0·45
	15 45	+0·10	21 10	—0·80		11 30	—0·30	16 20	—0·75
14	4 10	+1·60	12 00	—0·50	8	1 20	+1·25	8 45	—0·50
	16 15	+0·15	21 40	—0·80		13 00	—0·35	18 30	—0·85
15	4 40	+1·50	12 45	—0·70	9	1 50	+1·20	9 15	—0·70
	17 30	0·00	22 10	—0·80		14 00	—0·25	19 20	—1·00
16	5 30	+1·30	13 00	—0·70	10	2 15	+1·15	10 10	—0·70
	18 30	+0·05	23 30	—0·75		14 40	—0·25	20 00	—1·10
17	6 15	+1·10	13 15	—0·75	11	3 30	+1·25	10 40	—0·90
	18 25	+0·25	23 55	—0·40		15 45	—0·20	20 50	—1·15
18	6 30	+1·10	13 40	—0·70	12	3 50	+1·10	11 00	—0·90
	19 30	+0·20	-----	------		15 50	—0·20	21 30	—1·30
19	7 20	+0·85	0 00	—0·30	13	4 20	+1·00	11 30	—0·95
	20 30	+0·20	14 20	—0·60		16 40	—0·10	21 30	—1·00
20	7 50	+0·70	1 30	0·00	14	4 45	+1·00	11 50	—0·85
	23 15	+0·25	15 00	—0·65		17 30	+0·15	22 10	—0·70
21	8 10	+0·20	4 00	—0·15	15	5 20	+0·90	12 15	—0·70
	23 15	+0·55	14 50	—0·75		18 00	+0·30	23 30	—0·50
22	9 20	+0·10	6 00	0·00	16	6 20	+0·65	13 20	—0·75
	-----	------	15 50	—0·70		19 00	+0·40	-----	------
23	0 20	+0·65	6 40	—0·25	17	6 00	+0·55	0 10	—0·40
	9 45	—0·15	16 30	—0·80		19 45	+0·40	13 15	—0·80
24	1 10	+0·80	8 00	—0·35	18	6 40	+0·20	1 30	—0·30
	11 45	—0·30	17 40	—0·95		20 50	+0·35	14 00	—0·70
25	1 30	+0·90	9 15	—0·55	19	6 30	0·00	2 30	—0·20
	13 00	—0·45	18 10	—1·00		21 20	+0·50	14 00	—0·75
26	2 15	+1·10	10 00	—0·65	20	8 50	—0·20	5 40	—0·20
	13 40	—0·40	19 00	—1·05		23 00	+0·55	14 40	—0·75
27	2 40	+1·20	9 40	—0·75	21	[9 40]	[—0·30]	6 40	[0·30]
	15 00	—0·35	19 30	—1·05		[23 35]	[+0·65]	[15 35]	[—0·80]

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Feb. 22	10 30	—0·45	[8 05]	—0·50	Mar. 18	7 00	—0·20	3 00	—0·40
	-----	------	16 30	—0·90		19 50	+0·60	12 00	—0·70
23	0 00	+0·75	9 30	—0·75	19	7 25	—0·40	3 55	—0·35
	13 30	—0·60	18 10	—0·85		21 10	+0·65	12 30	—0·80
24	1 20	+0·95	9 45	—0·85	20	9 50	—0·55	6 30	—0·60
	13 45	—0·50	18 30	—1·00		22 15	+0·65	13 10	—0·70
25	2 30	+1·10	10 30	—0·85	21	10 10	—0·45	7 00	—0·60
	14 40	—0·30	19 45	—1·00		23 30	+0·75	14 00	—0·65
26	2 45	+1·20	10 30	—0·90	22	11 30	—0·40	8 00	—0·70
	15 30	—0·15	20 45	—1·00		-----	------	17 00	—0·65
27	3 30	+1·30	11 00	—0·85	23	0 10	+0·90	8 40	—0·60
	15 50	0·00	21 30	—1·00		12 00	—0·20	16 50	—0·70
28	4 30	+1·25	11 20	—0·95	24	0 40	+1·15	8 00	—0·70
	16 30	+0·15	22 00	—0·95		13 40	—0·05	18 25	—0·65
29	4 45	+0·90	11 20	—1·00	25	1 30	+1·20	8 30	—0·70
	17 30	+0·40	22 45	—0·80		14 15	+0·20	19 50	—0·65
Mar. 1	5 10	+0·65	12 00	—1·05	26	2 25	+1.25	9 30	—0·70
	18 20	+0·55	23 45	—0·55		15 00	+0·45	20 20	—0·60
2	5 10	+0·40	12 00	—1·10	27	2 40	+1·10	9 45	—0·75
	18 45	+0·60	-----	------		15 30	+0·65	21 15	—0·60
3	5 40	+0·05	1 00	—0·45	28	3 15	+0·90	10 15	—0·75
	20 45	+0·65	12 30	—1·05		16 15	+0·80	22 45	—0·50
4	6 00	—0·25	3 30	—0·35	29	3 50	+0·50	10 30	—0·85
	21 00	+0·60	13 00	—1·00		17 00	+0·90	23 15	—0·50
5	9 30	—0·40	7 00	—0·50	30	5 10	+0·40	11 00	—0·85
	22 50	+0·80	14 00	—0·85		18 00	+1·10	-----	------
6	10 30	—0·50	7 30	—0·55	31	5 15	0·00	1 30	—0·40
	23 50	+0·85	15 40	—0·80		19 00	+1.10	11 30	—0·90
7	-----	------	7 30	—0·75	Apr. 1	6 40	—0·20	3 15	—0·40
	12 20	—0·50	17 00	—0·65		20 30	+1·05	11 50	—0·90
8	0 50	+0·95	8 30	—0·75	2	8 30	—0·40	4 30	—0·55
	13 50	—0·40	18 30	—0·90		21 15	+1·05	13 10	—0·70
9	1 45	+0·90	9 35	—0·80	3	9 50	—0·45	6 15	—0·60
	14 00	—0·30	19 15	—0·90		21 50	+0·95	13 50	—0·55
10	2 20	+0·85	9 40	—0·80	4	11 45	—0·40	7 00	—0·75
	14 50	—0·15	20 20	—0·90		23 15	+0·90	15 45	—0·60
11	3 10	+0·90	10 20	—0·75	5	12 20	—0·30	7 30	—0·70
	15 30	—0·10	21 00	—0·95		-----	------	17 15	—0·55
12	3 45	+0·70	10 15	—0·90	6	0 15	+0·80	8 00	—0·70
	15 45	—0·05	21 15	—0·85		13 10	—0·20	18 10	—0·50
13	4 05	+0·60	10 30	—0·90	7	0 30	+0·65	8 00	—0·75
	16 30	+0·20	22 00	—0·70		14 30	+0·05	19 00	—0·55
14	5 00	+0·45	10 50	—0·75	8	1 20	+0·65	8 30	—0·70
	17 20	+0·25	22 30	—0·65		14 30	+0·20	20 00	—0·60
15	5 30	+0·20	11 15	—0·80	9.	2 10	+0·65	9 00	—0·70
	18 10	+0·50	23 50	—0·55		15 00	+0·40	20 30	—0·45
16	5 50	+0·10	11 20	—0·80	10	3 00	+0·55	9 30	—0·60
	18 00	+0·50	-----	------		15 15	+0·70	21 30	—0·50
17	5 20	0.00	0 30	—0·40	11	3 30	+0·50	22 15	—0·75
	18 40	+0·55	11 45	—0·80		16 00	+0·75	22 15	—0·50

High and low water, Honolulu, Hawaiian Islands—Continued.

Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
Apr. 12	3 30	+0·25	9 35	—0·80	May 7	0 50	+0·65	8 00	—0·70
	16 25	+0·80	23 10	—0·45		14 20	+0·70	20 20	—0·25
13	4 15	+0·20	10 10	—0·75	8	1 15	+0·50	8 15	—0·60
	16 50	+0·90	-----	------		14 30	+0·80	20 40	—0·30
14	4 30	—0·05	0 40	—0·50	9	2 30	+0·40	8 35	—0·70
	17 25	+0·90	9 45	—0·85		15 00	+1·00	21 45	—0·40
15	5 20	—0·15	1 15	—0·45	10	2 30	+0·20	8 40	—0·85
	18 40	+0·90	10 20	—0·85		15 40	+1·15	23 15	—0·45
16	6 00	—0·40	2 50	—0·50	11	3 30	+0·15	8 50	—0·80
	19 00	+0·85	10 00	—0·85		16 10	+1·25	-----	------
17	6 30	—0·45	3 30	—0·55	12	3 50	0·00	0 00	—0·50
	20 00	+0·75	11 00	—0·70		16 30	+1·25	9 20	—0·85
18	7 00	—0·60	4 30	—0·65	13	4 45	—0·15	0 20	—0·60
	21 40	+0·80	11 00	—0·65		17 30	+1·25	9 45	—0·90
19	12 00	—0·40	6 30	—0·55	14	5 40	—0·30	1 10	—0·60
	22 00	+0·80	14 30	—0·45		18 30	+1·20	10 20	—0·85
20	13 00	—0·25	7 00	—0·60	15	6 00	—0·30	2 30	—0·60
	23 10	+0·95	16 00	—0·40		18 50	+1·15	10 35	—0·75
21	-----	------	7 00	—0·60	16	7 00	—0·30	3 30	—0·60
	12 50	—0·10	17 15	—0·50		19 45	+1·00	11 15	—0·70
22	0 10	+0·85	7 30	—0·70	17	8 00	—0·40	3 30	—0·70
	13 45	+0·25	18 00	—0·50		20 45	+1·00	11 50	—0·55
23	1 00	+0·90	8 00	—0·70	18	10 45	—0·40	5 00	—0·75
	13 50	+0·45	19 40	—0·50		21 40	+0·85	13 00	—0·45
24	1 45	+0·85	8 40	—0·90	19	12 05	—0·15	5 45	—0·80
	14 30	+0·70	20 45	—0·55		22 20	+0·75	15 00	—0·30
25	2 40	+0·65	8 50	—0·95	20	12 45	+0·15	6 00	—0·80
	15 30	+1·15	21 50	—0·55		23 10	+0·65	17 30	—0·20
26	3 30	+0·35	9 00	—0·95	21	13 00	+0·45	6 40	—0·90
	16 00	+1·35	23 30	—0·50		23 45	+0·60	18 50	—0·30
27	3 55	+0·20	9 45	—1·10	22	-----	------	7 00	—0·95
	17 15	+1·40	-----	------		13 55	+0·75	20 15	—0·35
28	5 00	—0·10	1 00	—0·50	23	0 40	+0·25	7 00	—1·00
	17 50	+1·45	10 10	—1·00		14 15	+1·15	21 00	—0·50
29	5 45	—0·20	1 15	—0·60	24	2 00	+0·10	8 00	—1·10
	18 30	+1·40	10 50	—0·90		14 50	+1·40	22 25	—0·60
30	6 30	—0·30	2 30	—0·65	25	2 45	—0·05	8 30	—1·10
	19 30	+1·30	11 40	—0·75		15 30	+1·40	[23 35]	[—0·70]
May 1	7 00	—0·40	3 30	—0·60	26	[3 35]	[—0·20]	9 10	—1·20
	20 00	+1·10	11 25	—0·60		16 15	+1·50	-----	------
2	10 00	—0·45	6 30	—0·65	27	4 30	0·40	0 45	—0·80
	21 40	+1·00	14 30	—0·35		17 25	+1·50	9 45	—1·10
3	11 15	—0·25	6 15	—0·65	28	5 30	—0·50	1 45	—0·85
	22 50	+1·05	14 30	—0·20		18 30	+1·45	10 30	—0·90
4	12 30	+0·10	7 00	—0·70	29	7 00	—0·40	2 30	—0·70
	23 20	+0·85	17 20	—0·25		19 30	+1·20	11 10	—0·80
5	-----	------	7 15	—0·70	30	7 40	—0·40	3 30	—0·85
	13 30	+0·40	20 00	—0·30		20 00	+1·00	11 45	—0·60
6	0 15	+0·75	7 30	—0·80	31	9 20	—0·30	4 15	—0·80
	13 45	+0·50	19 30	—0·25		21 00	+0·85	12 30	—0·50

High and low water, Honolulu, Hawaiian Islands—Continued.

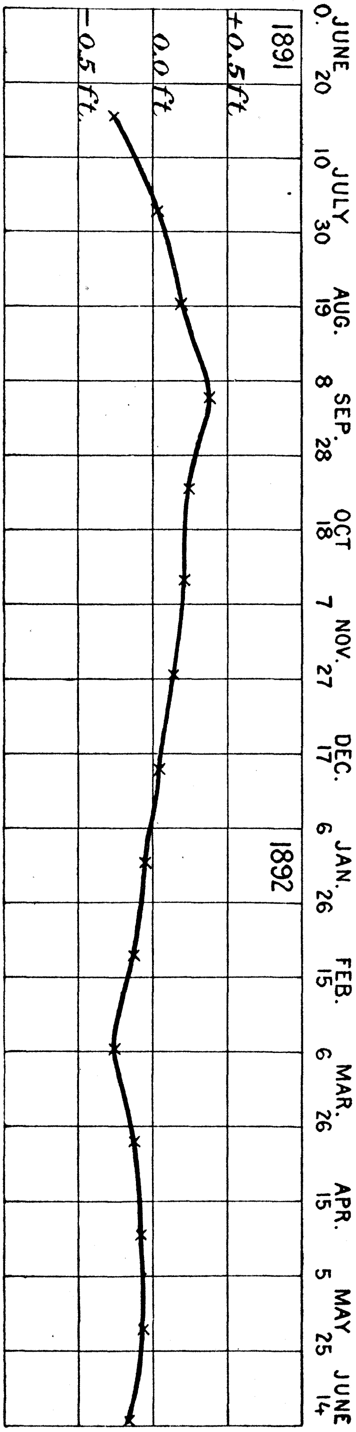
Date.	High water.		Low water.		Date.	High water.		Low water.	
	Corrected time.	Reduced height.	Corrected time.	Reduced height.		Corrected time.	Reduced height.	Corrected time.	Reduced height.
1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*	1892.	*h. m.*	*Feet.*	*h. m.*	*Feet.*
June 1	11 30	—0·15	5 00	—0·75	June 16	10 45	—0·15	3 50	—0·90
	22 00	+0·70	13 50	—0·30		22 00	+0·80	13 30	—0·40
2	[12 05]	[+0·10]	5 25	—0·80	17	11 15	+0·05	4 30	—1·00
	[23 10]	[+0·55]	[15 40]	[—0·25]		22 00	+0·60	15 40	—0·25
3	12 40	+0·40	[6 10]	[—0·80]	18	11 30	+0·40	5 00	—1·00
	-----	------	17 35	—0·20		22 30	+0·30	17 40	—0·25
4	0 20	+0·40	7 00	—0·80	19	12 40	+0·80	5 15	—1·10
	13 00	+0·55	18 40	—0·35		23 50	+0·05	18 50	—0·30
5	0 30	+0·15	6 30	—0·90	20	-----	------	6 00	—1·10
	13 30	+0·70	20 00	—0·40		13 20	+1·00	20 20	—0·50
6	1 15	0·00	7 00	—1·05	21	0 30	—0·15	6 40	—1·10
	14 00	+0·80	21 15	—0·45		14 00	+1·30	21 45	—0·50
7	1 10	—0·05	7 30	—0·95	22	1 15	—0·30	7 30	—1·20
	14 30	+0·95	22 00	—0·60		14 40	+1·45	22 30	—0·70
8	1 45	—0·30	7 30	—1·05	23	2 30	—0·50	8 00	—1·20
	15 10	+1·10	22 50	—0·55		15 20	+1·50	23 40	—0·70
9	2 30	—0·35	8 00	—0·95	24	4 00	—0·45	8 40	—1·25
	15 30	+1·20	23 45	—0·60		[16 10]	[+1·50]	-----	------
10	3 50	—0·40	8 30	—1·00	25	[4 40]	[—0·40]	[0 15]	[—0·70]
	16 30	+1·30	-----	------		17 00	+1·55	9 20	—1·10
11	4 40	—0·40	0 20	—0·60	26	5 20	—0·35	0 45	—0·65
	16 55	+1·20	9 15	—1·00		17 45	+1·35	10 00	—1·00
12	5 30	—0·50	0 40	—0·80	27	6 00	—0·35	1 10	—0·65
	17 30	+1·05	9 30	—1·00		18 30	+1·20	11 15	—0·85
13	6 45	—0·60	2 30	—0·80	28	6 45	—0·25	2 45	—0·70
	18 30	+1·10	10 30	—0·95		19 30	+0·95	11 35	—0·70
14	7 00	—0·45	2 30	—0·75	29	7 30	—0·25	3 00	—0·80
	19 00	+1·05	10 50	—0·80		[19 45]	[+0·80]	12 30	—0·55
15	8 00	—0·35	3 00	- 0·75	30	[8 15]	[—0·20]	[3 45]	[—0·90]
	20 30	+0·80	12 00	—0·60		20 00	+0·60	12 40	—0·30

The means being taken for intervals of five days, and these means being again consolidated for each successive group of five, we have the following table:

Relative heights of mean sea level at Honolulu, Hawaiian Islands, from June, 1891, to June, 1892.

Mean date.	Mean sea level (five days).	Mean date.	Mean sea level (twenty-five days).	Mean date.	Mean sea level (five days).	Mean date.	Mean sea level (twenty-five days).
1891.	*Feet.*	1891.	*Feet.*	1891–'92.	*Feet.*	1891–'92.	*Feet.*
June 19	—0·22			Dec. 26	—0·10		
24	— ·42			31	+ ·03		
29	— ·22	June 29	—0·25	Jan. 5	— ·04		
July 4	— ·24			10	— ·01		
9	— ·16			15	+ ·05	Jan. 15	—0·04
14	— ·08			20	+ ·02		
19	+ ·13			25	— ·22		
24	+ ·02	July 24	+ ·03	30	— ·10		
29	+ ·07			Feb. 4	·00		
Aug. 3	·00			9	— ·18	Feb. 9	— ·11
8	·00			14	— ·16		
13	+ ·07			19	— ·12		
18	+ ·14	Aug. 18	+ ·19	24	— ·32		
23	+ ·36			29	— ·15		
28	+ ·40			Mar. 5	— ·28	Mar. 5	— ·24
Sept. 2	+ ·40			10	— ·26		
7	+ ·33			15	·19		
12	+ ·40	Sept. 12	+ ·38	20	— ·27		
17	+ ·34			25	·00		
22	+ ·44			30	— ·01	Mar. 30	— ·11
27	+ ·36			Apr. 4	— ·20		
Oct. 2	+ ·26			9	— ·05		
7	+ ·28	Oct. 7	+ ·25	14	— ·12		
12	+ ·17			19	— ·20		
17	+ ·18			24	— ·04	Apr. 24	— ·09
22	+ ·22			29	— ·08		
27	+ ·14			May 4	— ·02		
Nov. 1	+ ·18	Nov. 1	+ ·21	9	+ ·06		
6	+ ·18			14	— ·10		
11	+ ·32			19	— ·11	May 19	— ·08
16	+ ·13			24	— ·06		
21	+ ·14			29	— ·20		
26	+ ·22	Nov. 26	+ ·15	June 3	— ·09		
Dec. 1	+ ·12			8	— ·19		
6	+ ·12			13	— ·26	June 13	— ·17
11	+ ·20			18	— ·12		
16	+ ·01			23	— ·20		
21	+ ·05	Dec. 21	+ ·04				

These values are plotted in the accompanying illustration.



Variation of Mean Sea Level at Waikiki, Hawaiian Ids.

Magnetic, Gravity, and Latitude Observations in Connection with the Expedition to the Summit of Mauna Kea, and at some Subsequent Stations.

In June, 1892, the latitude determinations were discontinued at Waikiki, and Honolulu was occupied for magnetic and gravity observations. The magnetic work already done at Waikiki and Kahuku is, for convenience of reference, also given in what follows.

DESCRIPTION OF MAGNETIC INSTRUMENTS.

The theodolite magnetometer is the same as the one taken to Africa in 1889–'90. It is designated as No. 11, United States Coast and Geodetic Survey, and was remodeled and improved at the office in July, 1887. The telescope has an aperture of 2^{cm}. The horizontal and vertical circles are each 10^{cm} in diameter. The graduation is from left to right, and angles may be read to single minutes by means of two opposite verniers. The dimensions of the magnets are:

*$N\ L_{11}$ length $= 7{\cdot}1^{cm}$, diameter $= 0{\cdot}8^{cm}$
$N\ S_{11}$ " $= 5{\cdot}8$ " $= 0{\cdot}8$

The ring used in determining the moment of mass of the intensity magnet ($N\ L_{11}$) had the following dimensions (C. S. Schott, October 31, 1889):

r = inner radius = $1{\cdot}4749^{cm}$
r_1 = outer " = $1{\cdot}8906$
w = weight = $19{\cdot}48940$ grams

from which

$$M_0 = \tfrac{1}{2}\,(r^2 + r_1^2)\ w = 56{\cdot}0291$$

at $16^\circ{\cdot}7$ C. or $62^\circ{\cdot}0$ F.

Moment of mass at temperature $t = M_1$

$$M_1 = M_0\ [1 + 2\ e\ (t - t_0)]$$

where e = coefficient of expansion for 1° C. = 0·000019 and

$$\log M_1 = 1{\cdot}74841 + 0{\cdot}0000165\ (t - 16^\circ{\cdot}7)$$

The value of 1 division of scale of long magnet ($N\ L_{11}$) was determined five times during the season, giving a mean result of 3′·68. This, combined with the African value, 3′·72, gives a value of 3′·70, which is adopted in the reduction of the observations. Increasing scale readings correspond to decreasing circle readings.

The moment of mass of the long magnet ($N\ L_{11}$) determined at Washington by Mr. Braid is $95{\cdot}748 \pm 0{\cdot}094$ (C. G. S. units). This value, however, includes the moment of the small balancing ring (K). (See Appendix No. 12, Report 1890.) Deducting this we have for the

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*$N\ L_{11}$ designates new long magnet of No. 11.

moment of mass to be used in the work of 1891–'92 a value of 94·303 at a temperature of 16°·7 C.

$$\log M \text{ at temperature } t = 1{\cdot}97453 + 0{\cdot}0000106\,(t - 16^\circ{\cdot}7)$$

Temperature coefficient (q) of $N\ L_{11}$ = 0·00108 for 1° F. and 0·00194 for 1° C.

Induction factor (h) in C. G. S. units = 0·0457 ± 0·0006 (C. S. Schott, December 6, 1890).

Induction coefficient μ ($= mh$) (C. G. S. units) = 6·54 ± 0·08 at 62° F.

To correct oscillations for induction

$$\text{to } \log T^2 \text{ add } \log\,(1 + h\,H)$$

To correct deflections for induction

$$\text{to } \log \frac{m}{H} \text{ add } \log\left(1 + \frac{2\mu}{r^3}\right) = 0{\cdot}00020 \text{ for } r = 30{\cdot}54^{\text{cm}}$$

$$= 0{\cdot}00006 \text{ for } r = 45{\cdot}78^{\text{cm}}$$

First distribution coefficient of $N\ L_{11} = P = -4 \pm 4$ (C. G. S. units).

For short deflecting distance ($r = 30{\cdot}54^{\text{cm}}$) $\log\left(1 - \frac{P}{r^2}\right) = 0{\cdot}00182$

" long " " ($r = 45{\cdot}78^{\text{cm}}$) " " $= 0{\cdot}00082$

Reduction of magnetic moment (m) of intensity magnet ($N\ L_{11}$) to 16°·7 C. $= m_{16^\circ{\cdot}7} = m\,[1 + (t - 16^\circ{\cdot}7) \times 0{\cdot}00194]$

$\log m_{16{\cdot}7} = \log m +$ modulus $\times\ 0{\cdot}00194\,(t - 16^\circ{\cdot}7) = \log m + 0{\cdot}00084\,(t - 16^\circ.7)$

Values of magnetic moment (m) at 16°·7 C. of long magnet (N L_{11}), showing loss of magnetism.

[Observer: E. D. Preston.]

Station.	Date.	Magnetic moment at 16°·7 C. (C.G.S. units).	No. of sets.
Washington	1889·73	143·3	3
Azores Islands	·83	140·4	2
Cape Verde Islands	·86	140·7	1
Africa:			
Sierra Leone	·88	134·3	1
Gold Coast	·91	128·9	2
Loanda	·96	129·4	3
Cabiri	·97	135·0	2
Cape Town	1890·07	134·2	5
St. Helena, Jamestown	·15	133·9	2
" " Longwood	·17	133·7	3
Ascension Island, Georgetown	·22	133·8	3
" " Green Mountain	·33	133·7	3
Barbados	·33	133·3	3
Bermuda	·39	131·9	3
Hawaiian Islands, Polynesia:			
Waikiki	1891·62	129·6	3
Kahuku	·90	128·8	3
Honolulu	1892·42	127·9	3
Kawaihae	·50	128·5	3
Waimea	·52	128·0	1
"	·53	128·8	2
Kalaieha	·54	128·3	2
Waiau	·56	123·6	2
Hilo	·58	127·1	3
Napoopoo	·64	124·7	3
Lahaina	·65	125·0	3
Waimea A	·67	125·0	2
" B	·68	124·0	3
Nonopapa	·70	125·4	1

Summary of time and azimuth results in connection with magnetic observations.

Station.	Date.	Epoch.	Correction to chronometer.*	Adopted daily rate.†	Position of mark.	Adopted position of mark.
	1891–'92.	*h. m.*	*m. s.*		° ′	° ′
Waikiki	Aug. 10	8 23 p. m.	— 8 10·9	—17		
	11	8 19	— 8 27·6			
	13	8 12	— 9 2·2			
	15	8 00 a. m.			N. 1 53·0 E.	N. 1 52·2 E.
	15	5 30 p. m.			N. 1 51·4 E.	
Kahuku	Nov. 25	9 00 a. m.			S. 65 8·8 W.	S. 65 7·6 W.
	25	3 00 p. m.	— 1 54	—58	S. 65 6·4 W.	
	27	9 30 a. m.	— 3 37			
Honolulu ‡	June 10	9 00	+ 0 37	+ 2	N. 55 20·0 E.	N. 55 20·0 E.
Kawaihae	30	5 00 p. m.	+ 4 03	—10	S. 25 2·7 E.	S. 25 2·2 E.
	July 3	5 00	+ 3 33		S. 25 1·8 E.	
Waimea	9	9 30 a. m.	— 0 26	—17	S. 81 40·2 E.	S. 81 50·3 E.
	9	4 30 p. m.	— 0 42		S. 81. 51·4 E.	
	11.	9 30 a. m.	— 0 65		S. 81 58·3 E.	
Kalaieha	14	8 40	+ 3 50	—18	N. 63 47·7 W.	N. 63 48·3 W.
	15	8 40	+ 3 33		N. 63 54·6 W.	
	15	8 40 p. m.	+ 3 25		N. 63 45·3 W.	
Waiau	21	10 20 a. m.	+ 3 54	—27	N. 22 8·0 W.	N. 22 5·6 W.
	21	4 30 p. m.	+ 3 47		N. 22 3·2 W.	
Hilo §	30	7 50 a. m.	+18 28	+20	N. 72 41·0 E.	N. 72 37·6 E.
	31	9 40	+18 50	—56	N. 72 43·1 E.	
	Aug. 1	9 20	+17 46	— 1	N. 72 49·7 E.	
	1	3 30 p. m.	+17 45		N. 72 30·8 E.	
Napoopoo	17	4 30	— 5 48	—18	N. 78 18·7 W.	N. 78 22·7 W.
	19	9 10 a. m.	— 6 18	—22	N. 78 14·6 W.	
	20	2 45 p. m.	— 6 45		N. 78 28·8 W.	
Lahaina	23	9 30 a. m.	+ 0 10	—24	S. 0 51·4 E.	S. 1 00·4 E.
	24	9 00	[— 0 41]		S. 1 5·3 E.	
	25	9 20	— 0 38		S. 1 4·5 E.	
Waimea A	Sept. 2	8 30	+ 0 09	—18	S. 39 37·2 W.	S. 39 40·7 W.
	3	8 20	— 0 09		S. 39 44·2 W.	
Waimea B	5	8 25	— 1 02	—14	S. 74 35·3 E.	S. 74 33·8 E.
	6	8 25	— 1 16	—22	S. 74 26·5 E.	
	7	8 10	— 1 38		S. 74 39·6 E.	
Nonopapa	9	8 50	— 4 42	—18	N. 4 13·6 W.	N. 4 13·6 W.

* Bond chronometer No. 177.

† + = losing; — = gaining.

‡ At Honolulu chronometer Gowland, 3280, belonging to the Government Survey, was used. The azimuth was also furnished by Mr. C. J. Lyons, of that service.

§ At Hilo watch No. 7583 was used.

MAGNETIC OBSERVATIONS AT WAIKIKI.

These observations were made on August 11, 12, and 13, 1891. As it was necessary to continue the time, latitude, and gravity determinations throughout the year, an epoch was chosen for the magnetic work which would least interfere with the regular observations. Accordingly, about the middle of August, just before changing the groups of stars then being observed for latitude, the magnetic work was undertaken. This implied almost continual observation and computation from 6.30 a. m. to 11 p. m., and involved the determination of the magnetic declination, dip, and horizontal intensity, with three sets of observations for time and azimuth with the theodolite magnetometer, besides the regular work with the pendulum apparatus, the zenith telescope, and the meridian instrument in the observatory. This was accomplished without any assistance either by a recorder or aid. The limit of satisfactory work was probably reached in this scheme, as a full day's magnetic work, followed by five hours' night observations, about exhausts an ordinary observer's capacity for good work. The station was situated near the astronomical observatory and on the property of Mr. J. F. Brown. The sketch on page 581 gives the location.

Abstract of results, Waikiki, Hawaiian Islands.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1891.	° ′	° ′	° ′	° ′	° ′	° ′
Aug. 11	40 08	39 29	39 48	39 51	40 02	39 56
12	14	28	51	40 10	01	40 06
13	20	28	54	39 50	06	39 58

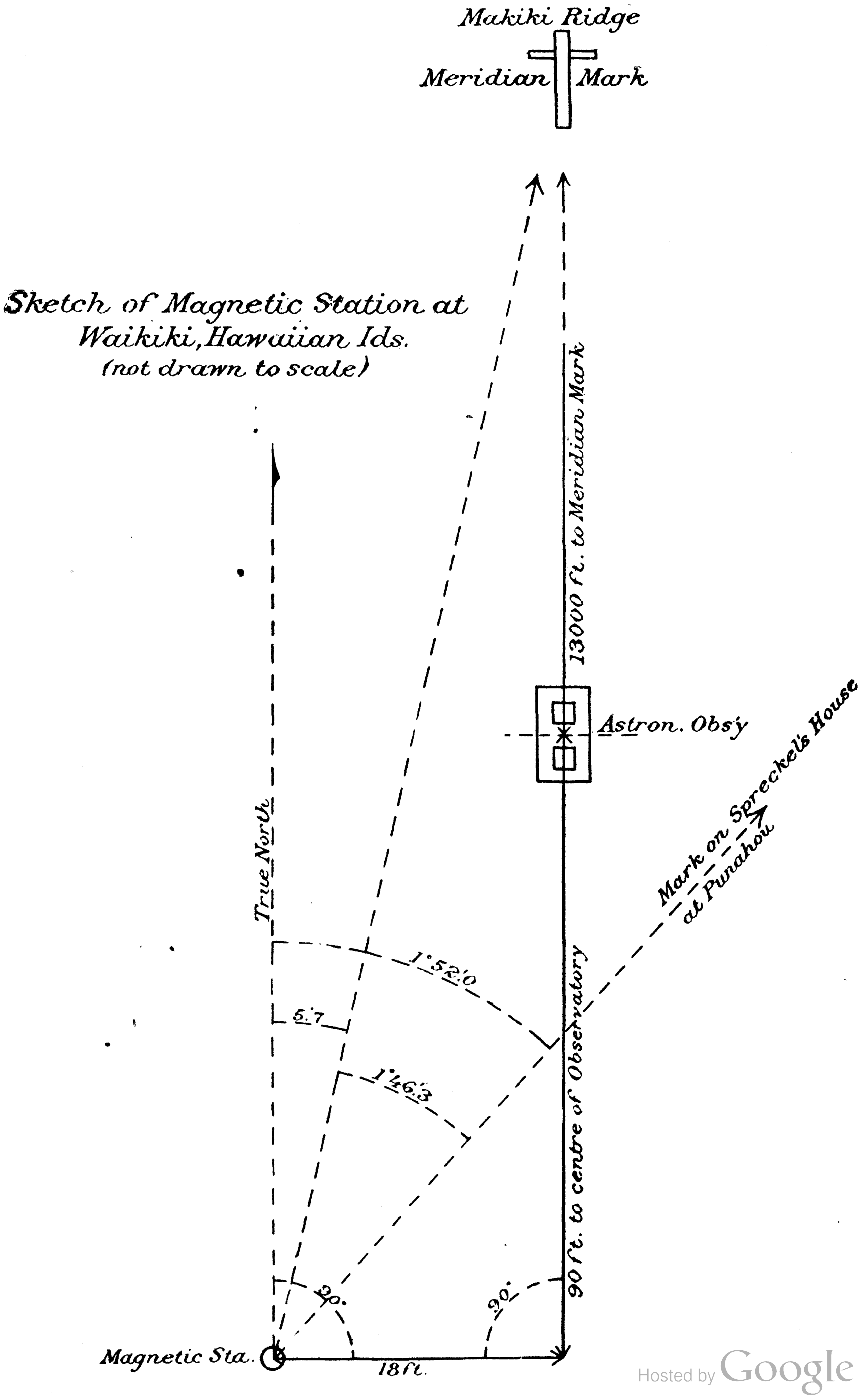
DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity = H.	Magnetic moment of magnet.
1891.	*d.*	° ′	° ′	*Dynes.*	
Aug. 11	28·72	10 05·3	39 52·0	0·2979	129·8
12	28·80	04·9	58·5	0·2971	129·6
13	-----	05·3	56·0	0·2992	129·4

MAGNETIC OBSERVATIONS AT KAHUKU, OAHU.

Taking advantage of an interval of one week in November, when my colleague on the international latitude work was necessarily absent from Waikiki, a set of magnetic determinations was made at the extreme north end of Oahu. Accompanied by Prof. W. D. Alexander, I left Waikiki on the morning of November 24, taking the steam cars from Honolulu to Ewa and riding from Ewa to Kahuku, a distance of 30 miles. We arrived at Kahuku late in the evening. Observations were begun early next morning and continued until about 1.30 p. m. on the 27th, when we started for Honolulu by way of the Pali. Stopping over night at Kualoa, Waikiki was reached the following afternoon and the observatory work was immediately resumed. Less than five days' absence were necessary for three full days' work at a station 40 miles from home, the distance being made both ways on horseback over a difficult road. The station occupied was situated in the front yard of the Kahuku ranch cottage. The cottage is about

[The diagrams hereafter given are not generally drawn to scale, being inserted simply to aid in reestablishing the position of the station in case it is desirable to repeat the observations at some future time.]

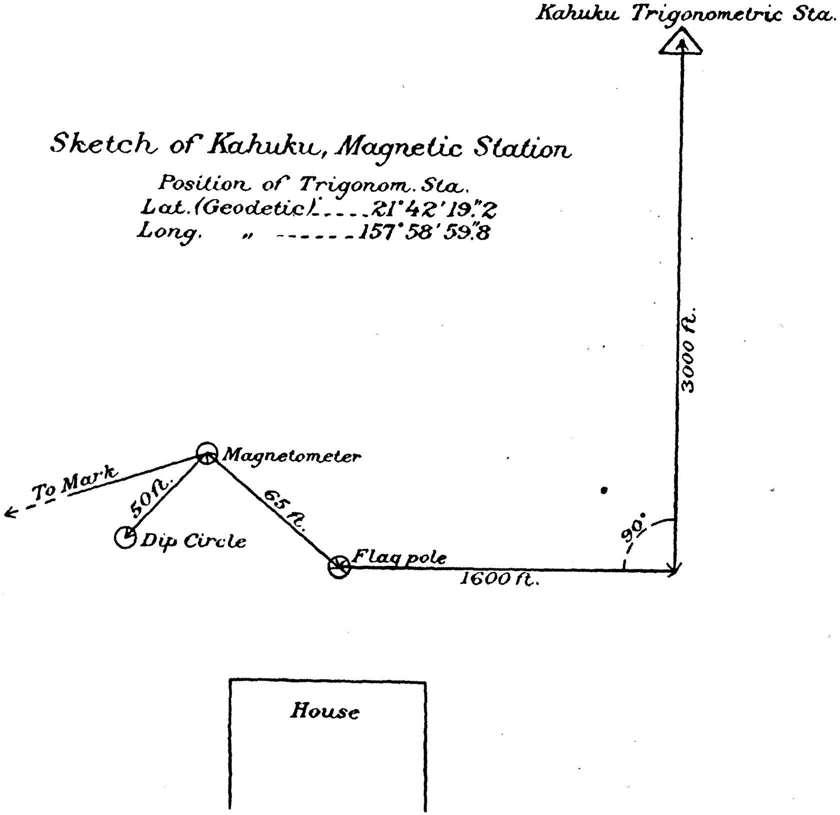


Sketch of Magnetic Station at Waikiki, Hawaiian Ids.
(not drawn to scale)

Makiki Ridge
Meridian Mark
13000 ft. to Meridian Mark
Astron. Obs'y
Mark on Spreckel's House at Punahou
True North
1°52'.0
5'.7
1°46'.3
90°
90°
90 ft. to centre of Observatory
Magnetic Sta.
18 ft.

three-fifths of a mile south and about one-third of a mile west of the trigonometrical station on the extreme north point of the island. The astronomical latitude of this station was determined in 1887.

The following sketch gives the relative positions:


Kahuku Trigonometric Sta.
Sketch of Kahuku, Magnetic Station
Position of Trigonom. Sta.
Lat. (Geodetic)....21°42′19.″2
Long. " ......157°58′59.″8
3000 ft.
Magnetometer
To Mark
50 ft.
65 ft.
Dip Circle
Flag pole
90°
1600 ft.
House

Abstract of results, Kahuku, Oahu.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1891.	° ′	° ′	° ′	° ′	° ′	° ′
Nov. 25	42 01	41 01	41 31	41 34	41 20	41 27
26	41 34	05	20	26	28	27
27	41	07	24	12	38	25

Abstract of results, Kahuku, Oahu—Continued.

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment of magnet.
1891.	*d.*	° ′	° ′	*Dynes.*	
Nov. 25	-----	10 16·4	41 29·0	0·2932	129·3
26	29·34	13·0	23·5	31	128·6
27	-----	14·7	24·5	44	128·4

OBSERVATIONS AT HONOLULU.

Gravity—Description of station.—The receiver was mounted on the window sill of the second story south room of the Kapuaiwa building, occupied by the Government Survey. Time observations were made in the observatory near by, and the chronometer used in noting the pendulum coincidences was connected with the chronograph so as to be used for the star observations in the evening. The oscillations were made generally in the daytime, as it was necessary for me to devote the evenings to either time observations at Honolulu or latitude observations at Waikiki, and, indeed, sometimes to both on the same night. The gravity determinations heretofore made at Honolulu were in 1883 and 1887. At the first-named time the station occupied was the cellar of the Young Men's Christian Association building, on the corner of Hotel and Alakea streets, and the instrument used was a pendulum of the reversible type (No. 3), measuring 1 yard between the knives In 1887 the Kapuaiwa building was occupied, and the pendulums were hung from an iron bracket embedded in the wall in the first story of the building. The determinations in this case were made with two pendulums, of which one was (No. 3) cited above, and the other (No. 4) of the same pattern, but having a distance of 1 metre between the knives. The small pendulums employed in 1891–'92 were therefore oscillated at Honolulu not only to connect the long series of observations made at Waikiki with a permanent station, but also to have an additional check on the work that was soon to follow on the Island of Hawaii. Moreover, the permanent station in Honolulu would thus be connected with our continental stations by means of a new form of instrument, which would materially strengthen the result.

The following are the pendulum observations and reductions. The mean of the direct and reverse results are combined with equal weights, irrespective of the number of individual observations in each position:

Pendulum observations. Honolulu, Hawaiian Islands.

[Observers: E. D. Preston, W. E. Wall.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
						Initial.	Final.				
			1892.		*Seconds.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_1	D	1	June 23	10	2263·0	4·8	3·4	25·93	73·4	767·0	630
		2	24	14	2254·3	4·9	1·4	28·52	119·4	766·2	583
	R	3	24	12	2260·8	4·8	3·5	28·40	214·6	765·8	497
		4	24	16	2263·1	4·7	3·2	28·25	229·0	765·5	485
		5	24	12	2262·5	4·7	3·5	27·90	221·0	765·3	492
	R	6	24	10	2266·5	4·8	3·9	26·64	200·0	766·0	514
		7	24	10	2267·5	4·8	3·9	26·34	189·0	766·4	525
B_2	D	8	25	6	2437·5	5·0	4·2	28·60	166·8	766·0	540
	R	9	25	4	2441·2	5·0	4·4	28·80	160·6	765·9	546
		10	25	4	2438·8	5·0	4·2	28·85	161·0	765·9	545
B_3	D	11	25	6	2614·2	4·6	3·8	26·28	97·4	765·6	608
		12	25	8	2613.1	4·8	3·7	25·93	88·2	766·0	617
		13	25	6	2617·5	4·7	4·0	25·48	82·0	766·4	624
		14	25	6	2615·8	4·8	4·1	25·22	65·2	766·4	640

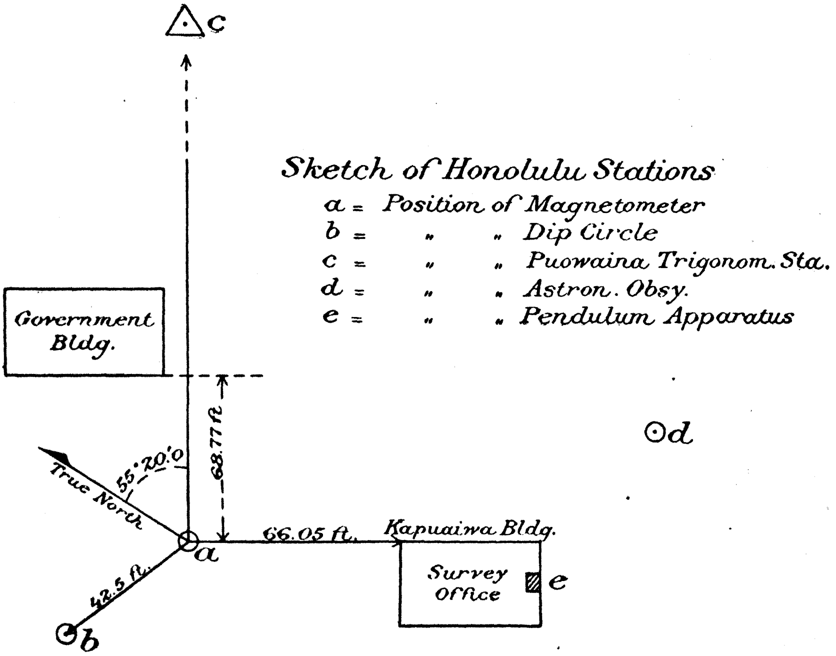
Reduction of pendulum observations, Honolulu, Hawaiian Islands.

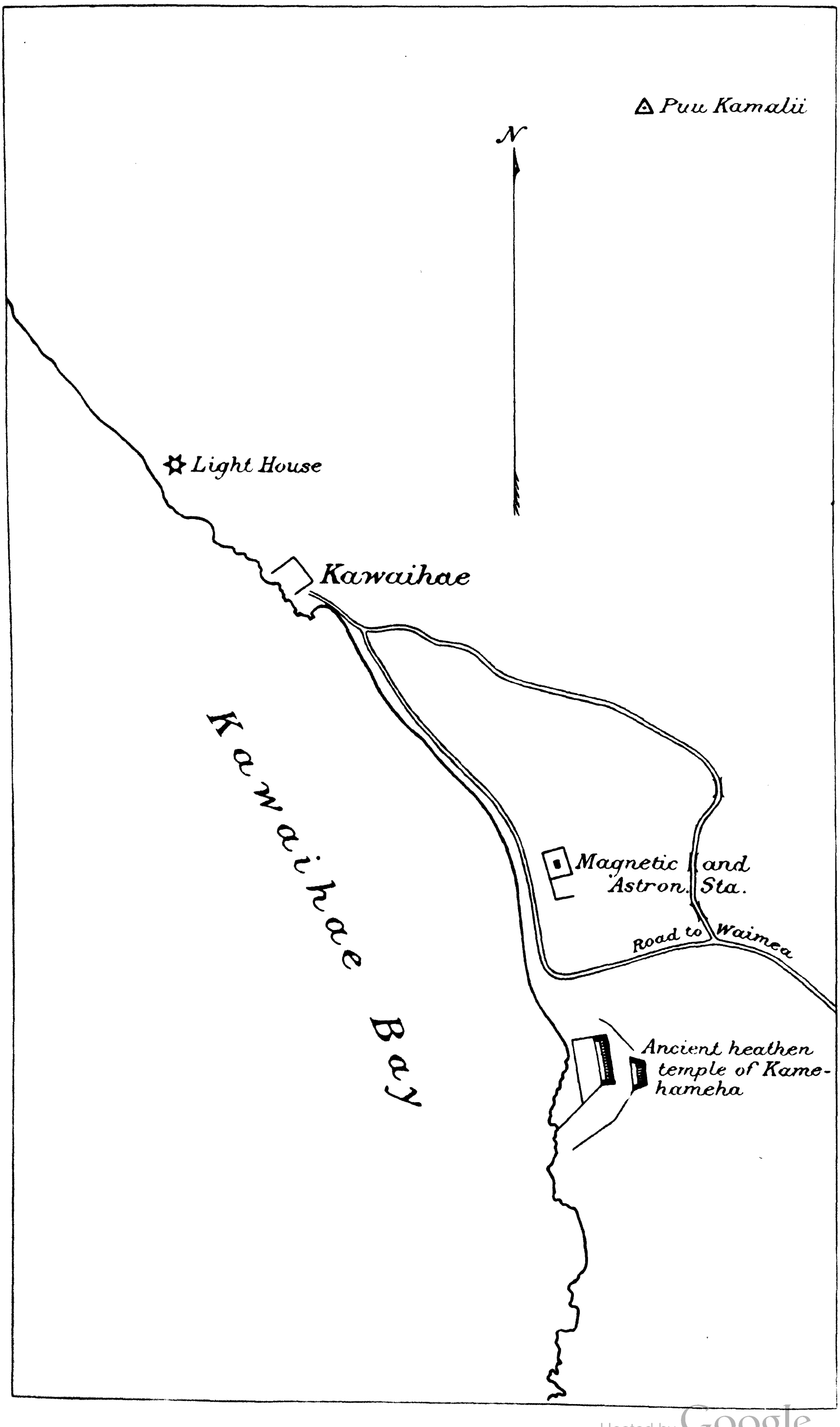
[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
	Arc.	Temperature.	Pressure.	Rate.	
Seconds.					*Seconds.*
0·501 1072	—59	—453	—103	+326	0·501 0783
1115	—31	—561	— 65	+326	784
1083	—61	—556	+ 2	+326	794
1071	—55	—549	+ 12	+326	805
1074	—59	—535	+ 06	+326	812
1055	—67	—483	— 11	+326	820
1050	—67	—471	— 20	+326	818
					0·501 0797
0·501 0277	—75	—564	— 31	+326	0·500 9933
0262	—78	—573	— 36	+326	901
0272	—75	—575	— 36	+326	912
					0·500 9920
0·500 9582	—62	—467	— 85	+349	0·500 9317
9585	—64	—453	— 92	+349	325
9569	—67	—434	— 98	+349	319
9575	—70	—424	—110	+349	320
					0·500 9320

MAGNETIC OBSERVATIONS AT HONOLULU.

The station was located in the public yard near the Government building. The magnetometer was set up in range with the northeast side of the Kapuaiwa building, and at a point which would give a clear line of sight past the Government building to the trigonometric station (Puowaina) on Punch Bowl hill. The dip circle was placed under the shade of the banyan tree, a few paces distant. Time and azimuth observations were not necessary at this station, as the standard clock of the Survey office was kept rated for the regular time service, and the direction from the magnetic station to the trigonometric point on Punch Bowl was accurately known from the Government triangulation. The azimuth of the line magnetic station – Punch Bowl, as furnished by Mr. C. J. Lyons, in charge of the Survey office, is north 55° 20′·0 east.




Puu Kamalii
N
Light House
Kawaihae
Kawaihae Bay
Magnetic and
Astron. Sta.
Road to Waimea
Ancient heathen
temple of Kamehameha

MAGNETIC OBSERVATIONS.

Abstract of results, Honolulu, Hawaiian Islands.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
June 2	41 02	40 10	40 36	40 42	40 54	40 48
3	40 55	13	34	34	46	40
4	41 10	22	46	46	52	49

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dynes.*	
June 2		10 14·7	40 42·0	0·2954	127·9
3	29·12	17·4	37·0	47	·9
4	29·00	16·7	47·5	51	·9

GRAVITY OBSERVATIONS.

Pendulum periods (Sidereal seconds)

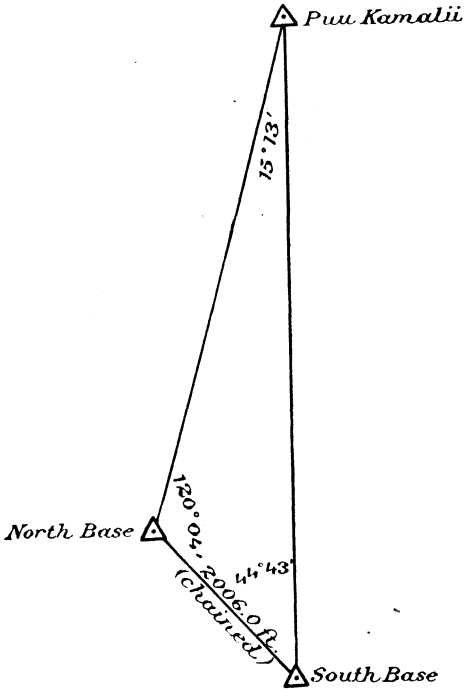
$$\begin{aligned} & \quad s. \\ B_1 &= 0{\cdot}5010797 \\ B_2 &= 0{\cdot}5009920 \\ B_3 &= 0{\cdot}5009320 \end{aligned}$$

KAWAIHAE.

Island of Hawaii.

Leaving Honolulu in the afternoon of June 28, on board the *Kinau*, we arrived at Kawaihae on the evening of the 29th. The party consisted of Prof. W. D. Alexander, surveyor-general; Messrs. W. E. Wall, W. W. Chamberlain, Louis Koch, and myself. The first observations were made on the 30th. The work at this station consisted of gravity, latitude, time, and magnetic determinations. The station was situated on the property of the Hon. Samuel Parker, to whom, as well as to the general superintendent, Mr. Paul Jarrett, our thanks are due for many acts of kindness. The connection between the astronomical station and the triangulation of the Government survey was carefully made. The general location of the property is between the boat landing and the Heiau of Kamehameha I, and about one-third the distance from the Heiau. Illustration No. 27 gives the relative positions. Illustration No. 26 shows the triangulation station and shore line.

Position of latitude station at Kawaihae, Hawaii.



Distance from Puu Kamalii to north base = 5377·47 ft.
" " " " " south " = 6614·39 "
Z " " " " " = 7° 34′

		°	′	″
Geodetic	L Puu Kamalii =	20	03	28·80
"	dL = −	0	01	5·00
"	L' south base	20	02	23·80

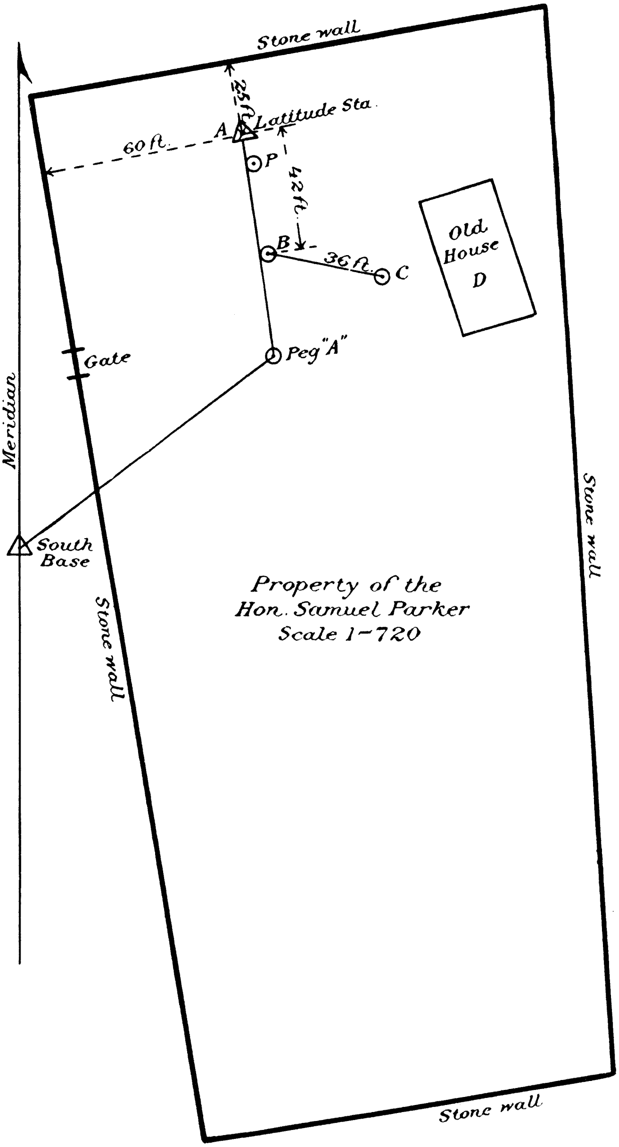
		°	′	″
Geodetic	M Puu Kamalii =	155	47	27·19
"	dM = +	0	00	09·14
"	M' south base =	155	47	36·33

Traverse, south base to Kawaihae latitude station:

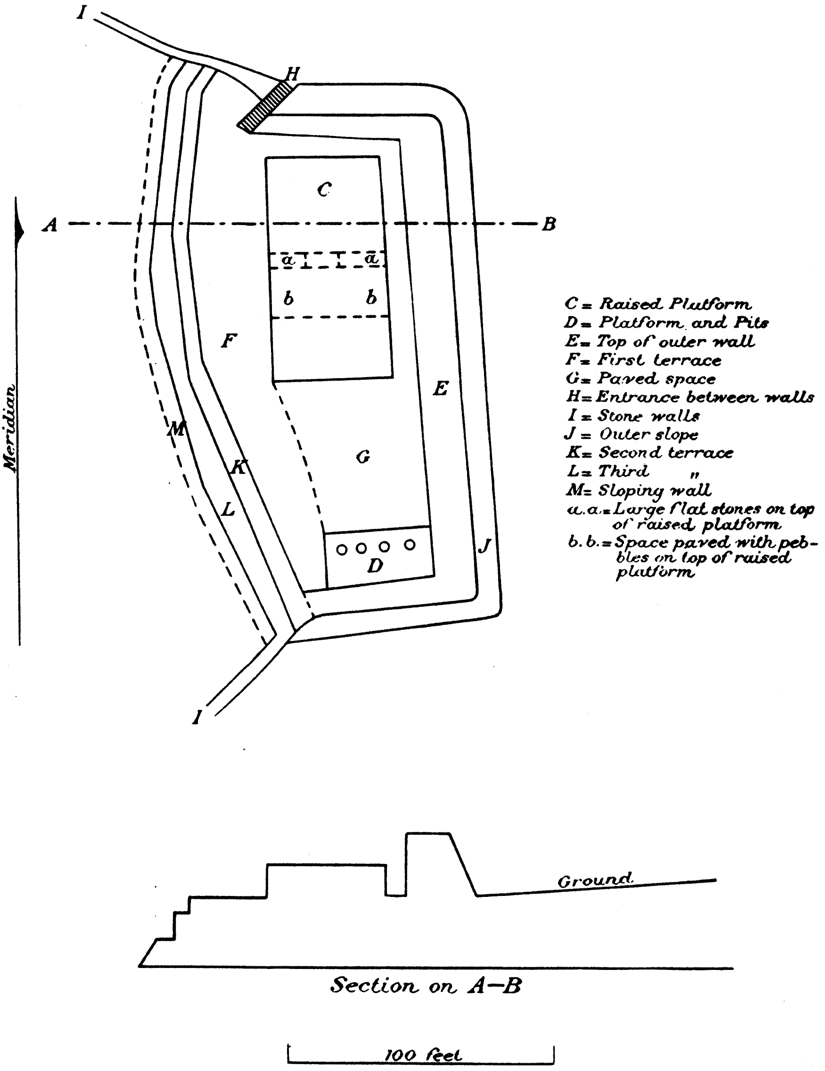
1. N 52° 43′ E., 100 ft. to peg "A"
2. N 6 55 W., 68.7 ft. to latitude station

Latitude station 128·77 ft. north of south base
" " 71·29 " east " " "

Location of Kawaihae Stations
with refercnce to So. Base



A = Latitude pier (Meridian telescope)
B = Dip Circle
C = Magnetometer
D = Ruins of stone house (John Young)
P = Pendulum Station



Section on A—B

Plan of Heiau of Puu Koholá at Kawaihae, Hawaii

	°	′	″
Latitude *L* south base	= 20	02	23·80
dL	= +	00	1·28
" *L′* latitude sta.	= 20	02	25·08

	°	′	″
Longitude *M* south base	= 155	47	36·33
dM	= −	00	0·70
" *M′* latitude sta.	= 155	47	35·63

At this station are the remains of an ancient temple, famous in early Hawaiian history as the scene of the first steps by which all the islands were consolidated under one government. It was here that Kamehameha betrayed and murdered his rival, Keoua, baked his body in an oven as a last indignity, and finally deposited it in the temple on the altar of the war god. He was henceforth recognized as the master of Hawaii. A sketch of this interesting Heiau from actual measurements has been furnished by Professor Alexander and is given here as a matter of curiosity. [Illustration No. 28.]

A remarkable feature of it is that although the early Hawaiians had no metal tools, and are to-day poor mathematical reasoners, their temples furnish examples of quite accurate right angles. One tested with a theodolite at Napoopoo was surprisingly near the truth.

Magnetic observations were made on July 1, 2, and 3. The pendulums were swung on the 3d, 4th, 5th, and 6th, and time and latitude were observed during the entire stay. We left on the morning of the 7th. The weather was generally favorable for work with the exception of one or two occasions when we had sudden gusts of wind from the mountains.* At this point preparations were made for the ascent of Mauna Kea. Packers and horses were engaged and the services of a guide secured. The connection of the astronomical station with the trigonometrical survey of the island was made at this station as well as at Kalaieha and Waiau by Professor Alexander. Meteorological observations were undertaken here in connection with those made at Honolulu and Hilo, to be used subsequently in determining the height of the mountain. The pendulum receiver was mounted on a large and massive cast-iron wheel, firmly embedded in the ground. This was part of the machinery of an old mill and was fortunately found near the spot where it was desirable to use it. The tent was erected close by and the flash apparatus was set up inside the tent. The meridian telescope was also erected so near that the tent fly served as a protection during the day, and at night was released and thrown back while the star observations were in progress. The following are the results of the pendulum observations:

---

* These storms are called mumúku in the native language, in contradistinction to the storms from the southeast, which receive the name of kona.

Pendulum observations, Kawaihae, Hawaiian Islands.

[Observers: E. D. Preston, W. E. Wall.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Barometer.	Pressure at 0° C.
						Initial.	Final.			
			1892.		*Seconds.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*
B_1	D	1	July 3	20	2184·0	4·9	3·0	26·78	765·6	695
	D	2	3	18	2187·8	4·9	2·8	25·22	765·5	697
	R	3	4	16	2173·4	4·6	2·8	26·53	766·0	696
	D	4	4	18	2165·6	4·9	2·9	27·85	766·2	693
	D	5	4	24	2156·2	4·9	2·5	29·66	766·1	688
	R	6	4	30	2143·0	4·9	2·0	31·53	765·4	683
B_2	D	7	4	14	2343·6	5·0	3·3	27·34	765·2	692
	R	8	4	16	2356·0	5·0	2·8	26·33	765·3	695
	R	9	5	18	2369·5	5·0	2·7	24·77	766·2	700
	D	10	5	20	2348·0	5·0	2·6	26·18	766·3	697
	D	11	5	18	2334·7	5·0	2·7	27·79	766·3	693
	R	12	5	28	2330·5	5·0	2·1	29·66	766·1	688
	R	13	5	36	2353·6	3·9	1·3	29·06	765·5	622
B_3	D	14	5	14	2500·4	4·6	2·8	27·49	766·0	694
	R	15	5	10	2498·5	4·6	3·0	26·84	766·2	695
	D	16	6	28	2532·2	4·2	1·7	25·88	766·9	626
	D	17	6	16	2494·4	4·8	2·8	27·64	767·0	695
	R	18	6	14	2482·9	4·7	2·8	29·06	767·2	691
	R	19	6	14	2485·7	4·7	2·3	29·56	767·2	690

Reduction of pendulum observations, Kawaihae, Hawaiian Islands.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
	Arc.	Temperature.	Pressure.	Rate.	
Seconds.					*Seconds.*
0·501 1473	—54	—489	—154	+333	0·501 1109
1454	—51	—424	—155	+333	157
1529	—48	—479	—155	+333	180
1571	—53	—533	—152	+333	166
1622	—47	—608	—148	+333	152
1693	—40	—686	—144	+333	156
					157
0·501 0690	—60	—512	—151	+316	0·501 0283
0634	—52	—470	—154	+316	274
0573	—51	—405	—158	+316	275
0670	—49	—464	—155	+316	318
0731	—51	—531	—152	+316	313
0750	—42	—608	—148	+316	268
0645	—22	—583	—096	+316	260
					287
0·501 0018	—48	—518	—153	+314	0·500 9613
0026	—50	—491	—154	+314	645
0 9893	—29	—451	—099	+314	628
1 0042	—50	—525	—154	+314	627
0089	—49	—583	—151	+314	620
0078	—42	—603	—150	+314	597
					622

MAGNETIC OBSERVATIONS.

Abstract of results, Kawaihae, Hawaii.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
July 1	38 32	37 46	38 09	38 04	38 15	38 10
2	42	48	15	05	14	10
3	37	41	09	13	16	14

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
July 1	29·18	9 18·7	38 09·5	0·3001	129·4
2	28·88	20·5	12·5	0·3025	128·2
3	....	22·5	11·5	0.3010	127·8

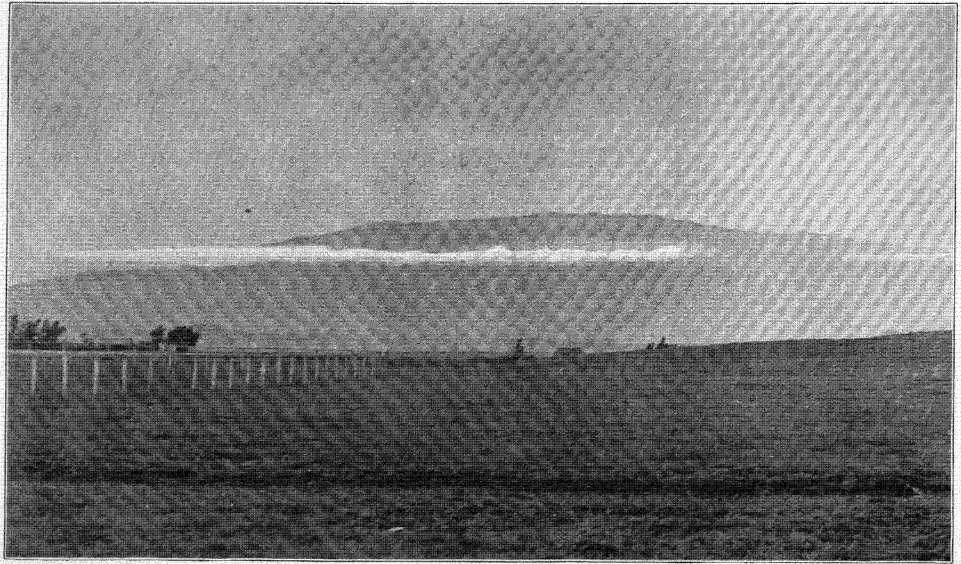
GRAVITY OBSERVATIONS.

[Sidereal seconds.]

		s.
Pendulum periods	B_1 =	0·5011157
	B_2 =	0·5010287
	B_3 =	0·5009622

DETERMINATIONS OF LATITUDE.

The latitude work at the three stations occupied for gravity was only of secondary importance. Only a limited number of pairs were selected for observation, and at Kalaieha the weather was so unfavorable that but three latitudes were obtained. The instrument used was a meridian telescope of 31 inches focal length, 2½ inches aperture, and magnifying power of 77. One revolution of the micrometer gave an angular value of 65″·85. One division of the latitude level is equal to 1″·66, and that of the striding level is 2″·21. The instrument is known as Meridian Telescope No. 2. In making the observations only one bisection was made, and the level was not read more than once, generally after the measurement with the micrometer. The results are not comparable in point of accuracy with those made at Waikiki with the zenith telescope, partly on account of the inferior accuracy of the instrument, but principally because the pier was generally constructed under poor conditions of stability. At Kawaihae and Kalaieha only a wooden pier was available, and at Waiau the great difficulty of trans-



MAUNA KEA, AS SEEN FROM WAIMEA, DISTANT 15 MILES, LOOKING SOUTHEAST.

Cloud belt at 10,000 feet elevation.

portation and labor made it necessary to construct a very small substructure. The following tables give the mean places and the individual results for latitude; *e* is the probable error and *μ* is the proper motion:

Mean places of latitude stars.

No. of star (U. S. C. and G. S. catalogue).	Mean right ascension (R. A.).			Mean declination (δ).			e^2	Proper motion (μ).
	1892.0.			1892·0.				
	h.	*m.*	*s.*	°	′	″	″	″
65	0	43	17	16	21	26·70	0·08	—0·210
73		49	01	23	02	35·70	·03	—0·042
78		51	26	22	50	03·63	·05	—0·054
1247	15	01	50	48	34	06·01	·03	+0·023
8313*		11	12	— 8	59	02·94	·02	—0·030
1257		13	48	2	10	27·21	·02	—0·524
1267		20	24	37	45	21·60	·02	+0·071
1284		30	06	27	04	41·89	·02	—0·107
1298		36	43	13	11	38·95	·08	—0·029
1302		38	12	26	38	16·52	·02	+0·029
1309		43	52	18	28	31·07	·02	—0·104
1317		46	32	21	18	09·86	·07	+0·005
1322		51	28	16	00	51·59	·02	—1·299
1333		57	39	23	06	16·19	·05	+0·025
1337	16	03	12	17	20	05·41	·03	—0·023
1342		07	55	5	17	51·29	·10	—0·005
1346		10	38	34	07	52·76	·03	—0·128
1361		21	34	37	38	24·51	·05	—0·022
1367		25	28	2	13	13·89	·01	—0·093
1383		35	49	12	36	17·63	·07	—0·022
1387		37	14	27	07	30·74	·08	—0·062
1390		39	53	34	14	17·07	·04	+0·058
1394		42	27	5	26	26·27	·10	—0·057
1416		59	58	— 0	44	36·71	·04	—0·006
1424	17	06	03	40	54	44·69	·05	+0·007
1428		09	44	14	30	49·27	·01	+0·022
1429		10	36	24	58	00·44	·04	—0·165
1436		13	33	10	58	54·60	·04	—0·094
1438		14	35	28	56	10·13	·07	—0·012
1449		19	57	37	14	44·45	·03	+0·010
1451		22	09	20	10	24·11	·04	+0·024
1457		25	56	2	48	21·10	·04	+0·014
1462		28	49	19	20	06·58	·06	—0·096
1471		33	05	24	22	27·88	·04	—0·004
1474		36	18	15	14	01·65	·50	—0·070
1477		38	03	24	37	07·43	·03	—0·118
1489		42	26	39	21	47·92	·04	0·000
1499		50	49	0	41	13·16	·09	—0·021
1522	18	02	08	8	13	13·35	·10	+0·019
1524		02	55	30	32	47·59	·04	+0·057

* Stone's Catalogue.

Results of latitude observations, Kawaihae, Hawaii.

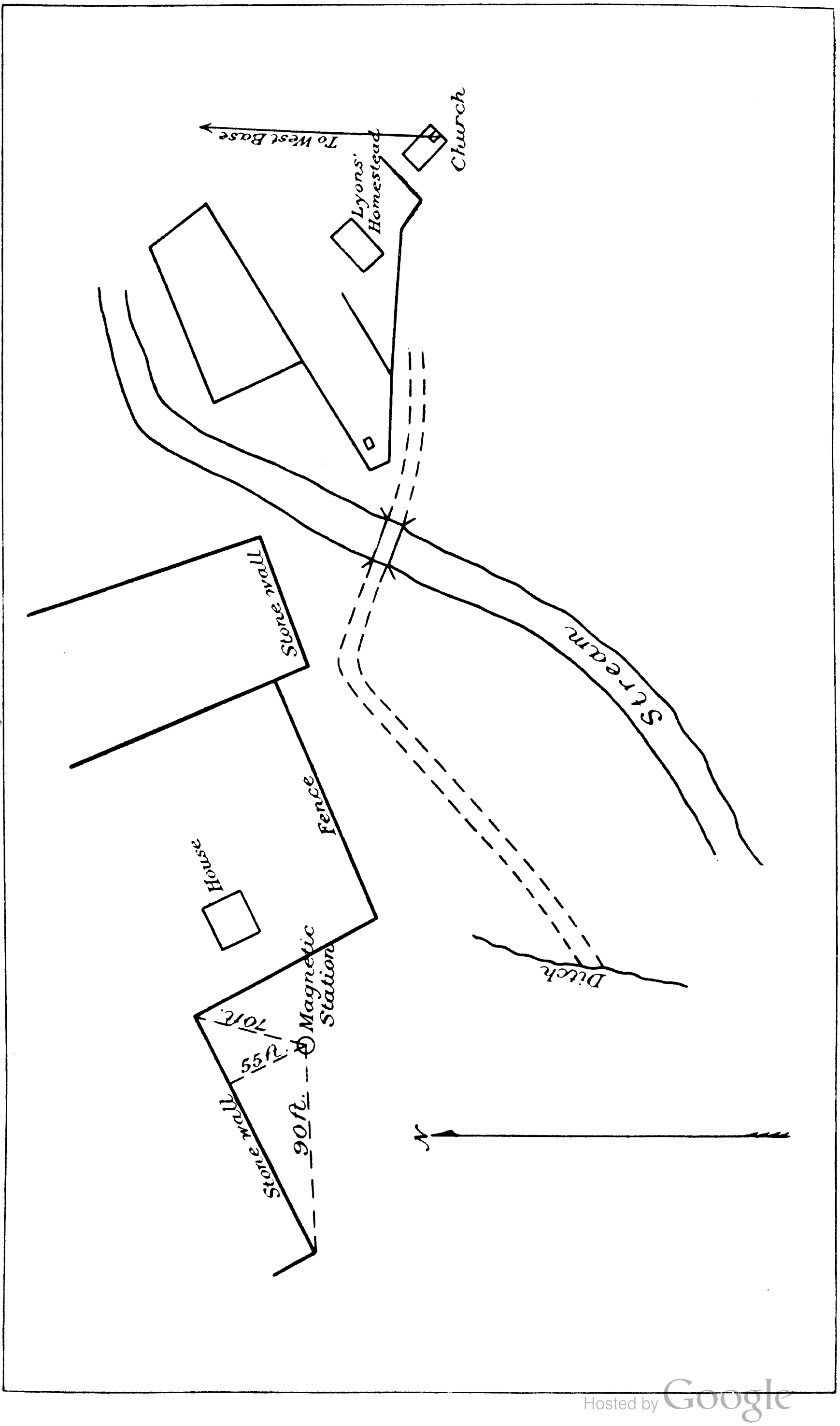
No. of pair.	No. of star (U.S. C. and G. S. catalogue).	Number of observations.	Latitude.
			° ′ ″
1	1243—8313	2	20 02 07·4
2	1257—1267	3	05·8
3	1309—1317	3	05·7
4	1284—1298	2	05·2
5	1333—1337	3	06·1
6	1361—1367	3	05·4
7	1383—1387	2	05·8
8	1390—1394	1	05·0
9	1436—1438	1	07·7
10	1449—1457	1	06·3
11	1474—1477	1	04·0
12	1489—1499	1	06·3
		23 (Total)	20 02 05·9 (Mean latitude)

Star No. 8313 is from Stone's Cape Catalogue of 12 441 stars.

WAIMEA.

[See illustration No. 29.]

On Thursday, July 7, 1892, Waimea was reached. At this station only magnetic observations were made. One station was at the west end of the base line of the Government survey and the other was identical with the station occupied in 1872 by Mr. C. J. Lyons. Additional horses and pack mules were engaged here for the ascent of Mauna Kea and preliminary arrangements made for the trip. Throughout our stay the work was much facilitated by Mr. W. L. Vredenburg. Our camp was established in his yard. The party was also recipient of other favors at his hands. Waimea is situated at an altitude of 2 600 feet above the sea level, with a moist atmosphere. Nearly every afternoon the trade winds bring in rain, so that the observations were made with difficulty. With so much regularity does the rain appear that it becomes to some extent a timepiece. In reply to the question, asked by one of our party, as to when school was dismissed for the day, the answer was that the school closed generally a quarter of an hour before the rain set in. The climate is well adapted to fruit, and the grazing land is of the best quality. The following plants were noticed in one of the gardens: Figs, wild tomatoes, bananas, coffee, pineapples, taro, mangoes, cauliflower, and sugar cane. The following is a sketch of the magnetic station occupied by Mr. Lyons in 1872; the other one is at the west end of the base line and needs no further description:



Waimea Magnetic Station

Abstract of magnetic results, Waimea, Hawaii.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
July 8	39 32	38 15	38 54	38 30	38 25	38 28
9	38 38	04	21	20	29	24
11	55	34	44	18	28	23

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.		° ′	° ′	*Dyne.*	
July 8	------	8 50·0	38 41·0	0·2966	128·0
9	------	9 03·0	22·5	78	129·3
11	------	04·2	33·5	86	128·4

NOTE.—On July 8 the magnetic station was at the west end of the base line of the Government survey. On July 9 and 11 the station was half a mile distant from the previous one, at a point occupied in 1872 by Mr. C. J. Lyons, of the Survey staff.

KALAIEHA.

Leaving Waimea at 7.25 a. m. on July 12, we arrived at Kalaieha at 5 o'clock in the evening, having passed the entire day in the saddle. The distance is about 30 miles. The road is not steep, as the elevation to be overcome between the two places is only 4 000 feet. This gives an average rise of 1 in 40, or an inclination of about 1½°. On the road specimens of lava were gathered at designated points in order to form a basis for estimating the average density of the rocks of the island. The route taken, as well as the points from which specimens were obtained, is shown in illustration No. 31. Kalaieha is situated on the Humuula ranch, which contains 237 000 acres, including a part of Hamakua. The tract runs down to the sea on the windward side and extends from the summit of Mauna Loa on the south to Mauna Kea on the north. At its widest region it is 20 miles broad. Its longest dimension is about 45 miles. On July 13 the stations were located and the tents and instruments put in position, and on the following day work was begun. The pendulum receiver was mounted on a large rock about 100 feet west of the house farthest to the west, and the latitude pier was within 2 or 3 feet of the pendulum in a southeast direction. The magnetic station was 200 feet due north of the pendulum. A general view of Kalaieha is shown in illustration No. 32. The prominent peaks along the path to the summit are identified by rectangular coordinates.

LOCATION OF PROMINENT PEAKS ON MAUNA KEA (ELEVATION, 13,825 FEET).

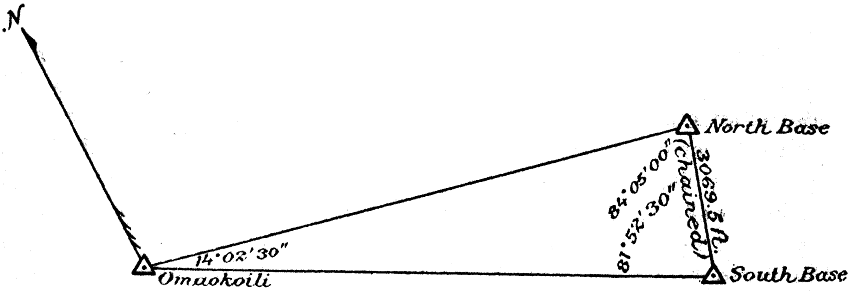
The important points on this mountain are to be found in illustration No. 32 at the intersection of vertical and horizontal lines, as follows:

Vertical.	Horizontal.	Name of peak.
w	1	= Waiau = location of gravity latitude and magnetic station.
b	1	= Poliahu.*
a	1	= Ku-ka-hau-ula = highest peak; the trigonometric station is near this point.
c	1	= Ke-one-he-he'e; trail to summit passes to right of this hill.
e	2	= Ka Lepe a Moa; trail passes between this and *e*—2.
k	1	= Omahulua.
g	2	= Kole.
h	2	= Loaloa.
f	2	= Hookomo.

---

* "Poliahu is a poetical name, being that of the demigoddess with snow mantle who haunts Mauna Kea. See Legend of Laieikawai. I therefore propose to attach it to this nameless peak. The rest are the genuine native names."—[W. D. Alexander.]

Geodetic position of Kalaieha Latitude Station.



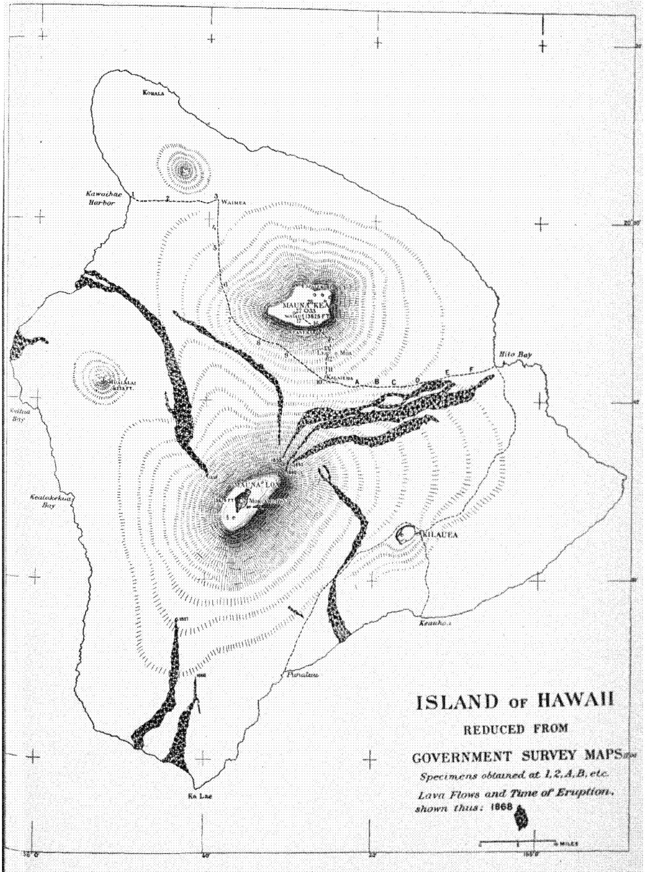
Geodetic *Z* Omaokoili to north base = 288° 00′ 40″

Distance from " " " " log (feet) = 4·0977463

" " " " " " log (metres) = 3·5817786

		°	′	″
Geodetic *L* Omaokoili from Aahuwela	=	19	43	13·63
d L	=	—	00	38·40
" *L′* north base	=	19	42	35·23

		°	′	″
Geodetic *M* Omaokoili from Aahuwela	=	155	27	56·94
d M	=	—	02	04·68
" *M′* north base	=	155	25	52·26



ISLAND OF HAWAII

REDUCED FROM

GOVERNMENT SURVEY MAPS

Specimens obtained at 1, 2, A, B, etc.

Lava Flows and Time of Eruption, shown thus: 1868

Geodetic Z Kalaieha, north base to latitude station = 28° 56′ 00″
Distance " " " " " = 202·5 feet

		°	′	″
Geodetic L north base	=	19	42	35·23
dL	=	−	00	1·76
Geodetic latitude of latitude station	=	19	42	33·47

		°	′	″
Geodetic M north base	=	155	25	52·26
dM	=	+	00	1·02
Geodetic longitude of latitude station	=	155	25	53·28

The above position of Omaokoili depends on the correctness of a **short base measured** near Aahuwela and a chain of six triangles carefully measured. The error probably does not exceed 0″·20.

Pendulum observations, Kalaieha, Hawaiian Islands.

[Observers: E. D. Preston, W. E. Wall.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Barometer.	Pressure at 0° C.
						Initial.	Final.			
			1892.		*Seconds.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*
B_1	D	1	July 14	12	2129·6	5·1	4·0	14·77	604·4	572
	R	2	14	8	2128·1	5·1	4·0	14·36	604·4	573
	R	3	15	16	2112·8	4·0	2·7	16·61	605·2	570
	D	4	15	18	2106·7	5·0	3·5	17·04	605·3	568
	D	5	15	34	2110·6	5·0	2.2	16·99	605·0	568
	R	6	15	30	2121·2	5·0	2·4	15·76	604·7	571
B_2	D	7	15	22	2307·5	4·9	2·8	13·61	605·2	576
	R	8	15	14	2320·0	4·8	3·2	12·51	605·7	578
	R	9	16	12	2342·9	4·3	3·1	10·44	605·7	582
	D	10	16	20	2326·8	5·0	3·1	11·40	605·8	581
	D	11	16	32	2313·0	5·0	[2·3]	12·81	605·9	579
	R	12	16	28	2301·4	5·0	2·4	14·07	605·8	575
B_3	D	13	16	28	2439·6	4·9	2·1	14·77	606·2	574
	R	14	16	14	2427·9	4·9	2·9	14·97	605·9	573
	R	15	16	20	2431·5	4·8	2·7	14·77	605·4	573
	D	16	16	24	2446·7	4·8	2·3	14·16	605·0	574
	D	17	16	18	2456·4	4·7	2·9	13·36	605·6	576
	R	18	16	14	2459·0	4·7	3·0	12·76	606·0	578

Reduction of pendulum observations, Kalaieha, Hawaiian Islands.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
	Arc.	Temperature.	Pressure.	Rate.	
Seconds.					*Seconds.*
0·501 1767	—73	+ 10	—57	+258	0·501 1905
1774	—73	+ 27	—58	+258	928
1861	—39	— 67	—55	+269	969
1896	—63	— 85	—54	+269	963
1873	—44	— 83	—54	+269	961
1813	—46	— 32	—56	+269	948
					946
0·501 0858	—51	+ 58	—60	+269	0·501 1074
0799	—56	+103	—62	+269	053
0693	—48	+189	—65	+269	038
0768	—57	+149	—64	+269	065
0832	—45	+ 91	—62	+269	085
0886	—46	+ 39	—59	+269	089
					067
0·501 0269	—41	+ 10	—58	+269	0·501 0449
0318	—53	+ 1	—58	+269	477
0303	—49	+ 10	—58	+269	475
0239	—43	+ 35	—58	+269	442
0198	—51	+ 68	—60	+269	425
0188	—52	+ 93	—62	+269	436
					451

The latitude observations at this station were made with great difficulty. During the entire stay not more than four pairs could be obtained. The evenings were always either foggy or rainy, and as the telescope was mounted in the open air, it was often necessary to lift it from the Ys and take it inside the tent to be dried. The latitude was always made to give way for the time observations, as these were necessary for the success of the gravity work, which was the real objective point of the trip.

Results of latitude observations at Kalaieha, Hawaii.

No. of pair.	No. of star (U. S. C and G. S. catalogue).	Number of observations.	Latitude.
			° ′ ″
1	1298—1302	1	19 42 03·2
2	1309—1317	1	02·5
3	65— 73	1	03·1
4	65— 78	1	01·7
		4 (Total)	19 42 02·6 (Mean)

Abstract of magnetic results at Kalaieha, Hawaii.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
July 14	39 12	38 23	38 48	38 50	38 50	38 50
15	09	34	52	39	43	41
16	14	19	46	53	46	50

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
July 14	29.06	9 53·1	38 49·0	0·2949	128·5
15	-----	52·1	46·5	0·2958	128·1
16	-----	-------	48·0	------	-----

GRAVITY OBSERVATIONS.

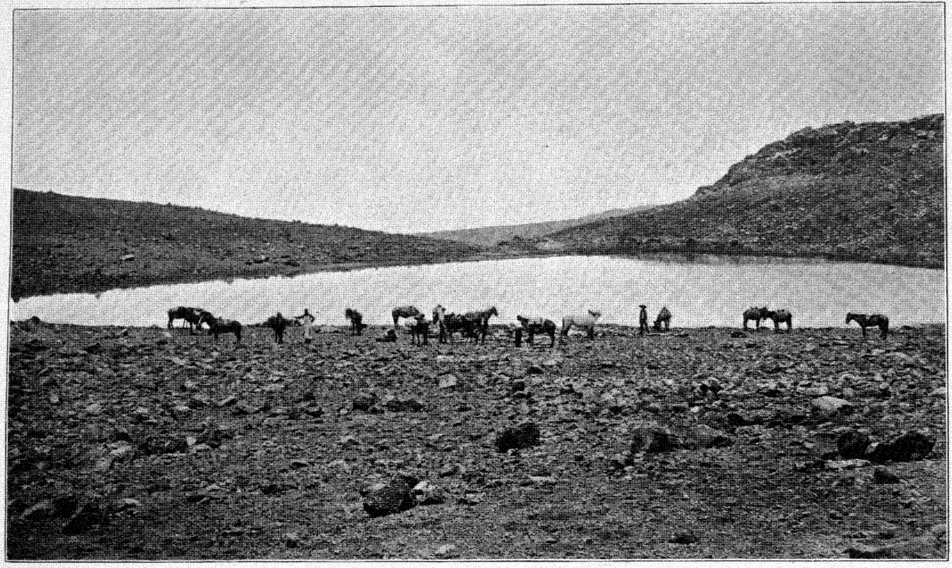
[Sidereal seconds.]

s.

Pendulum $B_1 = 0·5011946$

$B_2 = 0·5011067$

$B_3 = 0·5010451$



WAIAŬ LAKE, NEAR SUMMIT OF MAUNA KEA.
Elevation over 13,000 feet.

WAIAU.

[See illustration No. 33.]

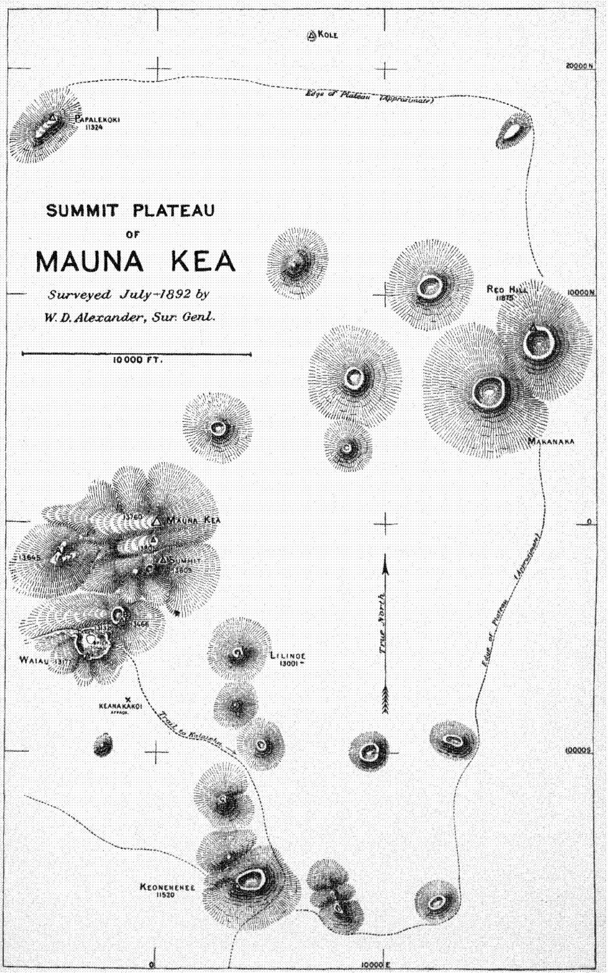
The instruments were dismounted at Kalaieha on July 18 and packed for the final ascent. The distance to the summit, in an air line, is about 7 miles, and the difference of elevation about 7 000 feet. The path, however, was about 12 miles in length, and Waiau is 700 feet below the summit, so that the average rate of rise was 1 in 11, or an angle of about 5½°. The amount of material to be transported to the top of the mountain was very great. Besides the astronomical, gravity, and magnetic instruments, and the provisions required to maintain the party on the summit long enough to complete the work, it was necessary to carry fuel, tents, and blankets, and enough cement to build a pier for the meridian telescope. The whole outfit was packed on 11 mules, and the party consisted of 11 persons, including 3 packers. Everything being in readiness, a start was made on the morning of July 19. Before getting well under way, however, a fog set in. Some of the pack animals became difficult to manage, and soon it was noticed that the mule carrying the magnetic instruments, probably the most delicate ones of the outfit, was missing. A halt was made and eight of the party started in search, but as the fog was now dense, our efforts were of no avail. After a couple of hours of delay it was decided to abandon the journey for the day. We all returned to Kalaieha, the animals were unpacked, and the day given up to hunting the lost instruments. The mule was found about 3 p. m. at the foot of the Omaokoili hills, some 3 miles distant.

On the following day we again set out at 7.40 a. m. At 11.40 a stop was made for lunch. The route passed between Lepe a Moa on the left and Kole on the right, and we now found ourselves at an altitude of about 10 000 feet. Continuing in the direction of Keonehehee, and climbing this cinder cone in a northeast direction (see illustration No. 34), we arrived at the plateau level at 2 p. m. The elevation of this point is 11 600 feet. The mamame trees were not seen above 10 000 feet, and the raillardia, the only remaining sign of vegetation, disappeared at 11 500 feet. From this point on, the path was over an unbroken landscape of lava. Some interesting pyramids of stone, built to commemorate Queen Emma's visit, were seen on the edge of the plateau, and at an elevation of 12 000 feet was found Keanakakoi, a famous quarry opened by the natives many centuries ago for the manufacture of battle axes. At an elevation of nearly 13 000 feet, near Lilinoe, a burying ground was found, where the ancient chiefs were laid to rest in the red volcanic sand. Before reaching the plateau the animals suffered considerably from the rarity of the atmosphere. On the flank of Keonehehee it was with great difficulty that they were driven—with tongues out and sinking ankle deep in the soft scoria at every step, they presented a pitiable picture indeed and seemed utterly regardless of the drivers' urging, whether with noise or whip. Although heavily laden, they repeatedly lay down, profiting by even a few minutes, when unobserved, to snatch a few moments' rest. Some were unable to reach the destination and had to be unloaded three-quarters of a mile from Waiau and turned loose to descend to the plains below. Their loads were repacked on stronger mules, which were sent back from the summit. The endurance of these mountain animals is remarkable. On the leeward side of the island, where it seldom rains, it is a common occurrence for them to pass eight days without water, and cases are on record where two weeks have elapsed between drinking times. Our camp was established on the banks of the lake known as Waiau. [See Frontispiece.] This is a body of water formed by the melting snow and gathered from the sides of an extinct crater. It is one of the highest bodies of water in the world, being at an elevation of over 13 000 feet. At 4 p. m. the baggage was all at the station and the animals were sent back to Kalaieha, as there is no provender within many miles of the place.

The boiling point of water on the summit (illustration No. 35) is about 186° F. The ranges of temperature during our stay were from 13° F. at night to 108° F. in the daytime, the thermometer having the same position at both times. The barometer stood at 18·30 inches at 54° F. We found the trade winds blowing at the summit, although the anti-trades are supposed by some to appear much below 14 000 feet elevation. The atmosphere was very clear. Many stars were observed before sundown with a small telescope. We had, of course, ice every night on the lake. With such extreme ranges of temperature there was much discomfort. Sleeping cots were not taken, as it was entirely too cold at night to lie off the ground. It was found necessary to make sleeping bags by sewing blankets together. Although for miles in every direction around Waiau there is an unbroken landscape of lava, and apparently nothing to support life, we saw spiders, butterflies, and flies during the stay. Around the shores of the lake the following plants were found growing, although the lake itself is several thousand feet above the last limit of vegetation. They were submitted to President D. C. Gilman, of the Johns Hopkins University, who kindly forwarded the list, as follows:

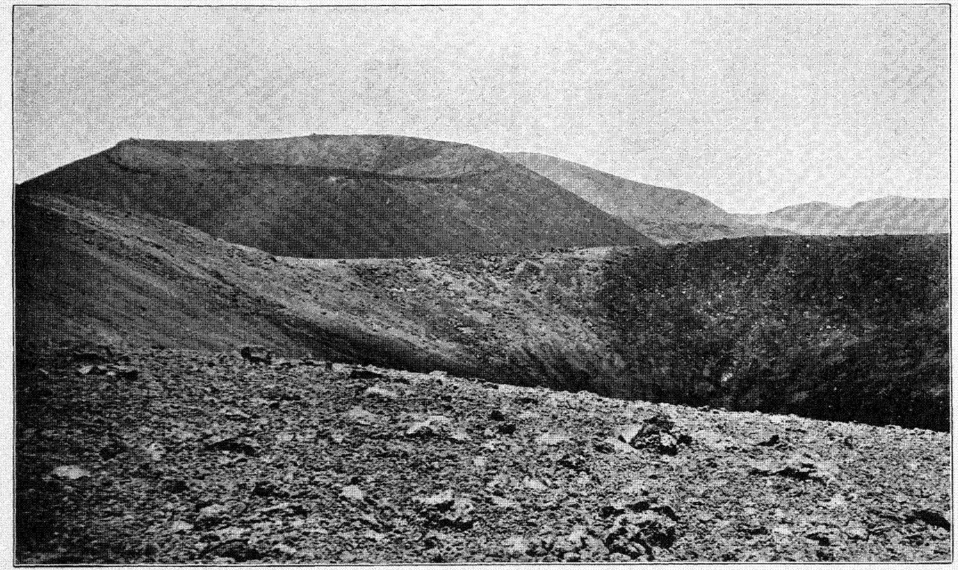
Cystopteris fragilis Beruh.
Trisetum glomeratum Trin.
Poa annua L., forma vel vaz.
Deschampsia australis Nees.

The first specimen was determined by Mr. John Donnell Smith, and the last three by Dr. George Vasey. All the above plants were found growing near the same locality, at an elevation of about 13 100 feet above sea level. See illustration No. 35 for summit view.


SUMMIT PLATEAU
OF
MAUNA KEA
Surveyed July 1892 by
W. D. Alexander, Sur. Genl.
10 000 FT.
KOLE
20000 N
Edge of Plateau (Approximate)
PAPALEKOKI
11324
RED HILL
11875
10000 N
MAKANAKA
0
13760
MAUNA KEA
13805
SUMMIT
13809
13645
13466
13137
WAIAU 13177
KEANAKAKOI
APPROX.
Trail to Kalaieha
LILINOE
13001
True North
Edge of Plateau (Approximate)
10000 S
KEONEHEHEE
11520
0
10000 E

U. S. Coast and Geodetic Survey Report for 1893. Part II.

No. 35



VIEW FROM KU-KA-HAU-ULA, THE SUMMIT OF MAUNA KEA, LOOKING SOUTHWEST.

Elevation 4,214 meters (13,825 feet).

The Geodetic Position of Waiau, Latitude Station.

	°	′	″
Latitude of Mauna Kea (primary triangulation)	19	50	01·63 N.
Longitude " " " " "	155	26	18·75 W.

Geodetic *Z* Mauna Kea to "Peak A" = 69° 26′ 00″
Distance from " " " " " log (feet) = 3·6563410
" " " " " " " log (metres) = 3·1403733

Geodetic $d\,L$ from Mauna Kea to "Peak A" = −15″·785
" L' of "Peak A" = 19° 49′ 45″·845

Geodetic $d\,M$ from Mauna Kea to "Peak A" = +44″·456
" M' of "Peak A" = 155° 27′ 03″·206

Geodetic *Z* "Peak A" to Waiau latitude station = 337° 18′ 45″·00
Distance from " " " " " " log (feet) = 3·583900
" " " " " " " " log (metres) = 3·067932

Geodetic dL' from "Peak A" to Waiau latitude station = −35″·087
" latitude of Waiau latitude station = 19° 49′ 10″·758

Geodetic dM from "Peak A" to Waiau latitude station = −15″·500
" longitude of Waiau latitude station = 155° 26′ 47″·706

Position of latitude station probably correct within 3 feet.

All the above longitudes are conventional and should be corrected by adding 2′ to them. The latitudes are derived from the main triangulation. The above computation was supplied by the Government Survey Office in Honolulu.

Pendulum observations, Waiau, Hawaiian Islands.

[Observors: E. D. Preston, W. E. Wall.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Barometer.	Pressure at 0° C.
						Initial.	Final.			
			1892.		*Seconds.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*
B₁	D	1	July 22	22	1992·7	5·0	3·5	10·09	477·0	459
	R	2	22	22	2020·9	5·0	3·4	7·57	477·2	464
	R	3	23	26	2049·4	5·0	3·1	3·95	477·3	470
	D	4	23	20	2011·5	5·0	3·7	7·57	477·8	464
	D	5	23	22	1977·7	5·0	3·5	11·20	478·1	458
	R	6	23	20	1955·2	5·0	3·5	13·91	478·1	454
B₂	D	7	23	24	2087·1	5·0	3·1	15·77	478·0	451
	R	8	23	24	2078·1	5·0	3·2	16·85	477·8	449
	R	9	23	16	2071·6	5·0	3·7	17·09	477·6	449
	D	10	23	20	2065·0	5·0	[3·5]	16·85	477·5	449
	D	11	23	18	2092·2	5·0	3·6	14·07	477·2	453
	R	12	23	24	2126·9	5·0	3·2	11·45	477·2	457
B₃	D	13	24	18	2221·1	4·9	3·5	13·71	478·7	456
	R	14	24	16	2238·8	4·0	3·1	12·10	478·9	458
	R	15	25	20	2359·5	4·6	2·9	3·30	478·5	472
	D	16	25	16	2338·1	4·5	3·0	4·70	478·6	470
	D	17	25	18	2309·4	4·6	3·1	7·02	478·9	466
	R	18	25	42	2272·1	4·5	1·9	10·15	479·0	461

Reduction of pendulum observations, Waiau, Hawaiian Islands.

[Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; arc infinitely small; sidereal time.]

Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
	Arc.	Temperature.	Pressure.	Rate.	
Seconds.					*Seconds.*
0·501 2578	—63	+204	+32	+309	0·501 3060
2401	—62	+308	+28	+309	2984
2228	—57	+459	+23	+309	2962
2460	—67	+308	+28	+309	3038
2674	—63	+158	+33	+309	3111
2820	—63	+045	+36	+309	3147
					3050
0·501 2008	—57	— 32	+39	+309	0·501 2267
2058	—59	— 77	+40	+309	271
2097	—67	— 87	+40	+309	292
2136	—63	— 77	+40	+309	345
1976	—65	+ 39	+37	+260	247
1781	—59	+147	+34	+260	163
					264
0·501 1281	—62	+ 54	+35	+260	0·501 1568
1191	—44	+120	+33	+260	560
0618	—49	+486	+22	+260	337
0715	—49	+427	+23	+260	376
0849	—52	+331	+27	+260	415
1027	—34	+201	+31	+260	485
					457

Abstract of magnetic results at Waiau, summit of Mauna Kea, Hawaii.

DIP.

Date.	Needle No. 1.						Needle No. 2.					
	N.		S.		Mean.		N.		S.		Mean.	
1892.	°	′	°	′	°	′	°	′	°	′	°	′
July 21	38	60	38	09	38	34	38	42	38	14	38	28
22		57		13		35		24		38		31
23		54		17		36		41		42		42

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).		Mean dip.		Horizontal intensity.	Magnetic moment.
1892.	*d.*	°	′	°	′	*Dyne.*	
July 21	30·02	10	21·0	38	31·0	------	-----
22	29·24	--------			33·0	0·2950	123·5
23	-----	--------			39·0	0·2950	123·6
24	-----	10	24·4	---------		------	-----

ABSTRACT OF GRAVITY RESULTS.

[Sidereal seconds.]

$$\begin{aligned} & \qquad\qquad\quad s. \\ \text{Pendulum } B_1 &= 0{\cdot}5013050 \\ B_2 &= 0{\cdot}5012264 \\ B_3 &= 0{\cdot}5011457 \end{aligned}$$

The latitude of the station was determined by fifty-two measures on sixteen pairs of stars, as follows:

Latitude of Waiau.

No. of pair.	No. of star (U. S. C. and G. S. catalogue).	Number of observations.	Latitude.		
			°	′	″
1	1257—1267	2	19	48	51·7
2	1298—1302	3			51·0
3	1309—1317	3			54·6
4	1322—1333	3			50·8
5	1342—1346	4			51·2
6	1361—1367	3			52·3
7	1383—1387	4			53·3
8	1390—1394	4			52·4
9	1416—1424	4			54·0
10	1428—1429	4			52·2
11	1436—1438	4			52·5
12	1451—1462	4			52·1
13	1471—1474	3			50·4
14	1471—1477	2			50·6
15	1489—1499	3			53·0
16	1522—1524	2			49·4
		52 (Total)	19	48	52·0 (Mean)

The geodetic positions of the three stations on Hawaii, as communicated by Professor Alexander, are given in the third column following:

Latitudes.

Stations.	Astronomical latitude.	Geodetic latitude.	Astronomical minus geodetic.
	° ′ ″	° ′ ″	″
Kawaihae	20 02 05·9	20 02 25·1	—19·2
Kalaieha	19 42 02·6	19 42 32·4	—29·8
Waiau	19 48 52·0	19 49 10·8	—18·8

The above table shows that there is a deflection of the plumb line toward the north at all three stations, and the deflection at Kalaieha appears to be much more marked than at either of the other stations. By reference to illustration No. 31 it will be seen that we should expect a greater deflection at Kalaieha than at either of the other two. The deflection at Ka Lae, the extreme southern point of the island, appears to be about 1′ 29″. This result is from work done by myself at this point in 1887 with zenith telescope No. 1, and a subsequent triangulation by Mr. J. S. Emerson, of the Hawaiian Government Survey, previous to 1891.

FROM WAIAU TO HILO.

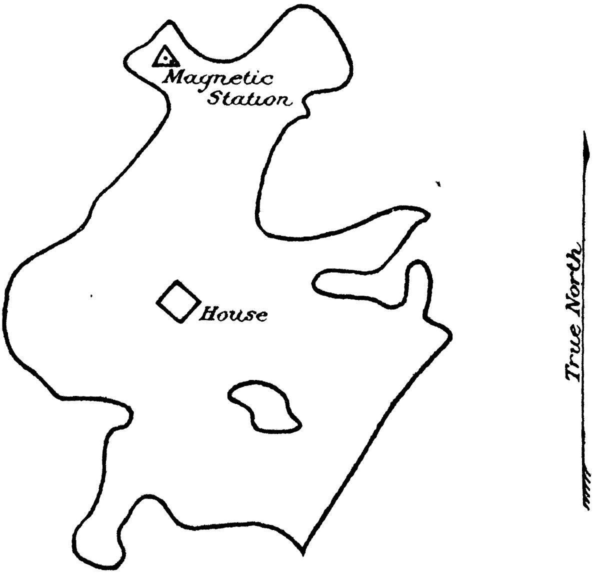
The last observations were made at Waiau on the evening of July 25. The next morning the animals arrived from Kalaieha. They were packed during the forenoon of the 26th, and at 1.30 p. m. we started down. We reached the Humuula ranch (Kalaieha) at 5.45 p. m., having stopped an hour at Keanakakoi. On the 27th the instruments and baggage were all repacked. The party separated at this place, some going down the windward side of the mountain to Hilo, and the others returning to the sea over the same route taken in the ascent. This course was necessary because magnetic observations were to be carried on at Hilo, and as it was impossible to transport the baggage to the steamer on this side of the island, it was sent to Waimea and then to Kawaihae. We left Kalaieha at 6 a. m. on July 28th with a small pack train and a guide. The path is about 30 miles long, very rough, and much of the way over sharp lava. We were supplied with horseshoeing implements. This is a requisite to everyone making the trip. The lava is so hard and sharp that if a shoe is lost the horse's foot is badly cut in a few minutes, and neither persuasion nor force will induce him to continue the route unshod. Many carcasses were seen along the road, of animals that had been killed or left to die, as there is nothing by the wayside to support life. Just before arriving at Hilo we passed through 1¾ miles of swampy woods, which consumed two hours in crossing. Hilo was reached at 7.30 in the evening, after having spent thirteen hours in the saddle.

The photographic plates exposed on the mountain were developed the next day, and on Saturday, the 30th, magnetic observations were begun.

HILO.

The station occupied was on Cocoanut Island, about a mile and a half from the court-house. This station was chosen because magnetic work had been done here by other observers. The following is a sketch of the island, showing the location of the magnetic station and its position with reference to the house near by.

Sketch of Mokuola (Cocoanut Island.)



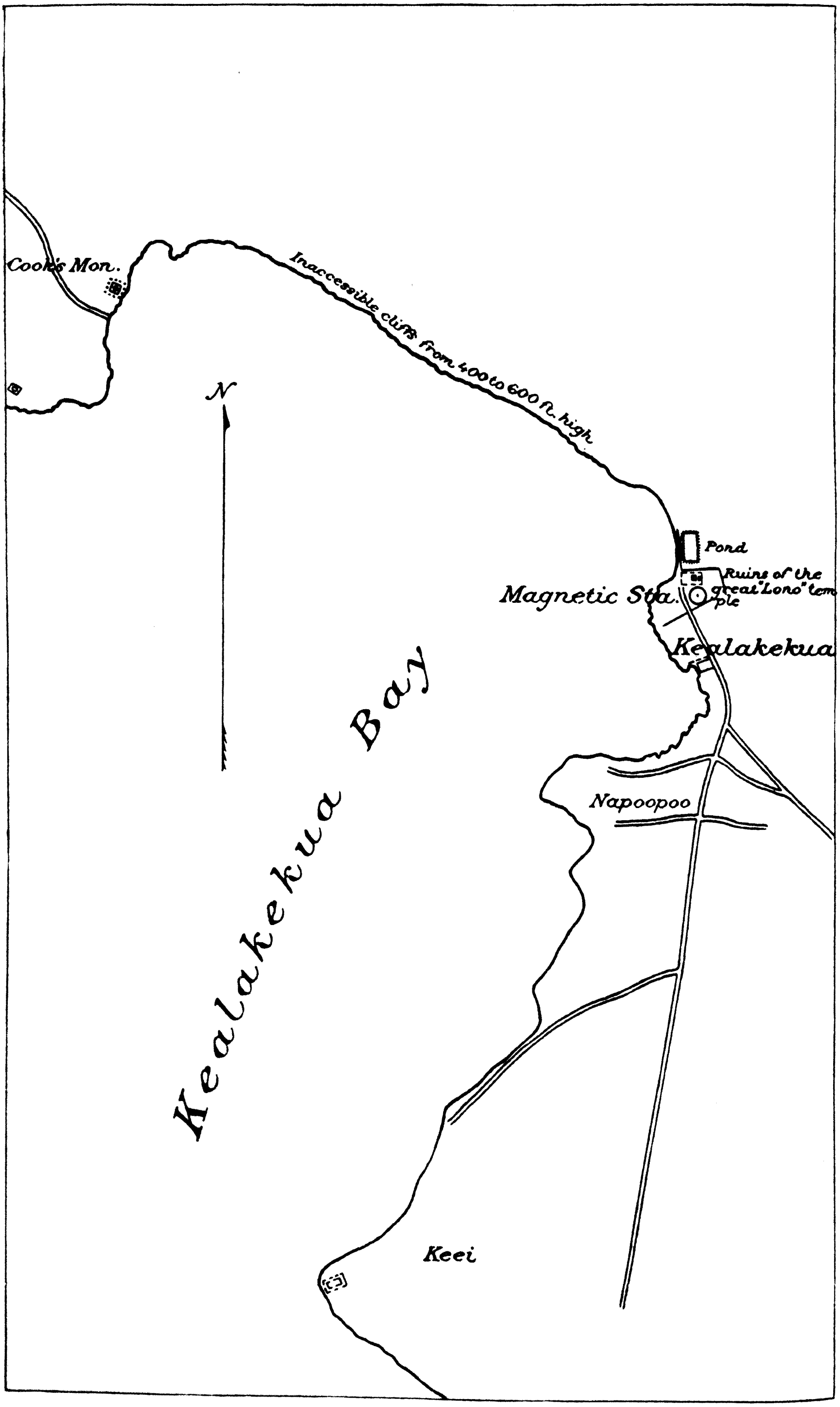
Abstract of magnetic observations at Hilo, Hawaii.

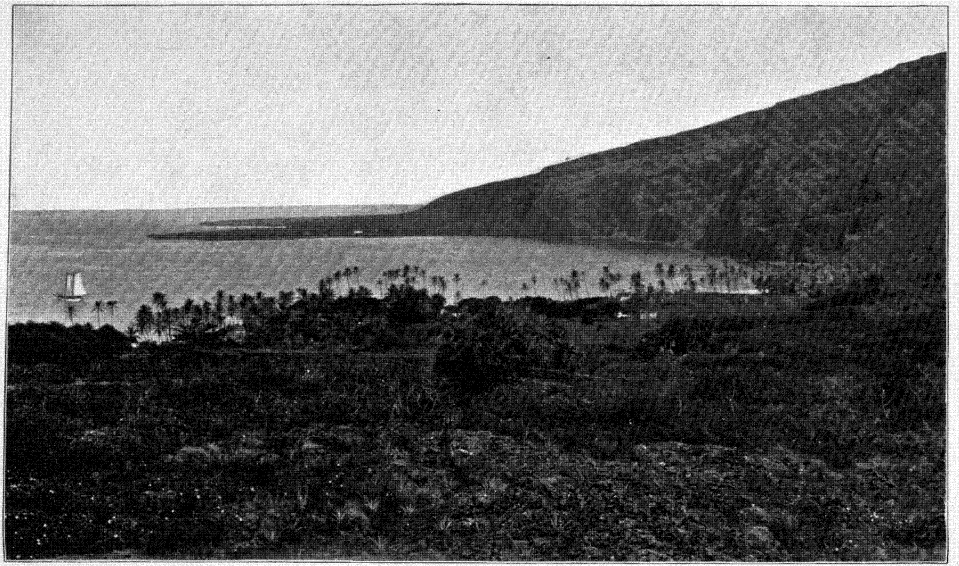
DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
July 30	39 43	39 03	39 23	39 14	39 23	39 18
31	39	04	22	20	32	26
Aug. 1	50	12	31	25	15	20

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
July 30	-----	8 26·1	39 20·5	0·3064	127·0
31	29·00	25·3	24·0	·3064	127·5
Aug. 1	28·76	18·9	25·5	·3057	126·8
2	-----	19·4	--------	------	-----


Cook's Mon.
Inaccessible cliffs from 400 to 600 ft. high
N
Pond
Ruins of the great "Lono" temple
Magnetic Sta.
Kealakekua
Kealakekua Bay
Napoopoo
Keei



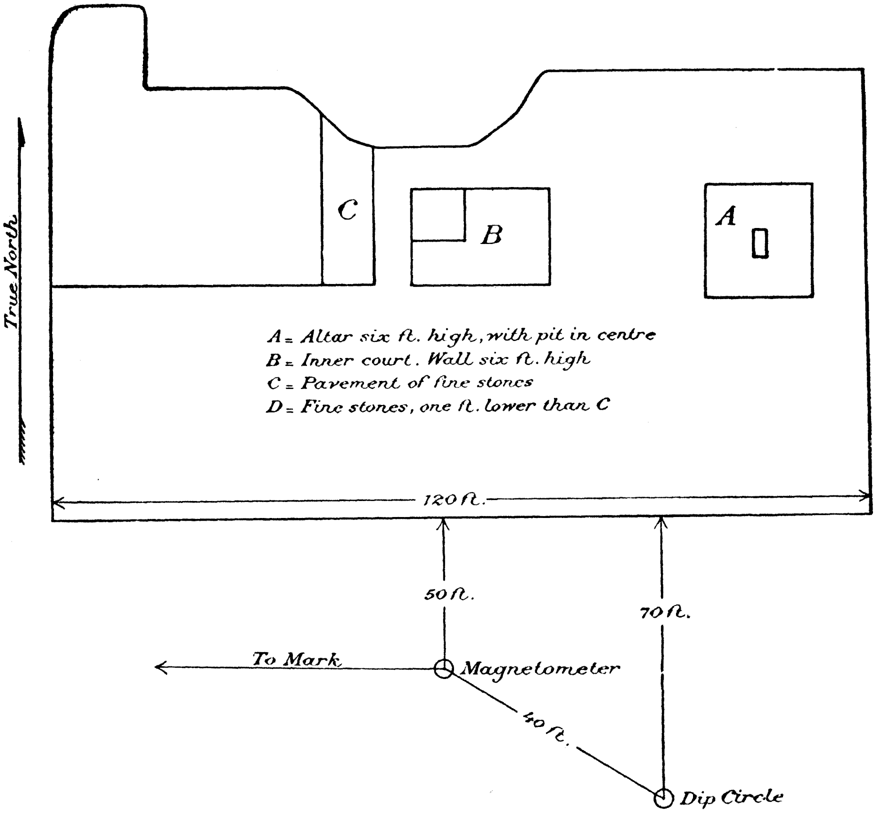
KEALAKEAKUA BAY, LOOKING NORTHWEST.

In December, 1878, Mr. C. J. Lyons found an easterly declination of 7° 40′ at this same station. A comparison with the above would give an annual increase of east declination of three minutes.

NAPOOPOO, HAWAII.

On August 16 I left Honolulu for Kealakeakua Bay, where Captain Cook had his observatory in 1779. Arriving on the 17th, the observations were begun the following day. With the aid of a map and verbal instructions at the Government Survey Office, in Honolulu, I was able to find the spot occupied by the great navigator, and the magnetic instruments were placed practically in the same locality. (See illustrations 36 and 37.)

The following sketch (which is only approximately drawn to scale) shows the situation with reference to the Heiau:


True North
C
B
A
A = Altar six ft. high, with pit in centre
B = Inner court. Wall six ft. high
C = Pavement of fine stones
D = Fine stones, one ft. lower than C
120 ft.
50 ft.
70 ft.
To Mark
Magnetometer
40 ft.
Dip Circle

The following readings were made at the magnetometer station:

	°	′
Cook's monument	4	12
Heiau on Kalaemamo Point	353	06
Pole on Kamehameha Heiau	15	32

Abstract of magnetic results at Napoopoo, Hawaii.

DIP.

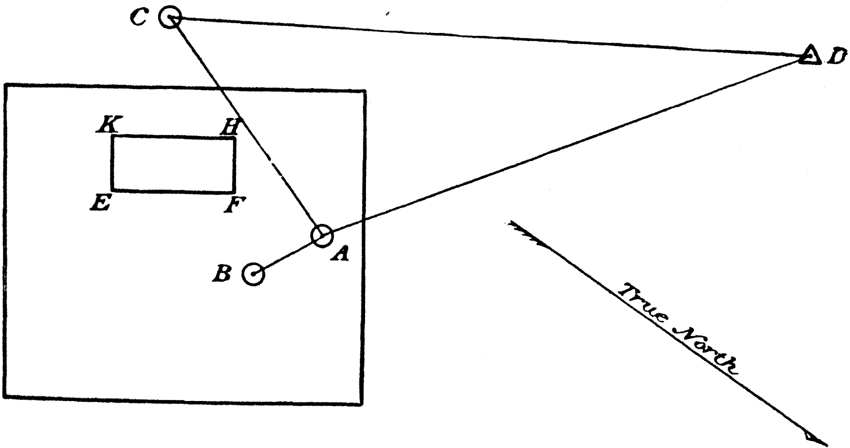
Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
Aug. 18	37 56	37 22	37 39	37 44	37 34	37 39
19	37 46	36 57	22	22	46	34
20	38 08	37 10	39	54	30	42

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
Aug. 18	28·30	9 09·2	37 39·0	0·3035	124·0
19	-----	10·9	28·0	0·3027	124·7
20	28·38	05·7	40·5	0·3011	125·3
21	-----	06·6	---------	------	-----

LAHAINA, MAUI.

Leaving Napoopoo at 3 p. m., on August 22, we arrived at Lahaina at 7 a. m. the following morning. Observations were made on the 23d, 24th, and 25th. The station chosen was in the court-house yard, as shown in the following sketch (approximately):



A = Position of magnetometer.
B = Dip circle.
C = Flag pole.
K H F E = Court-house.
D = Latitude pier and gravity station, 1883.

Readings at A.		*Distance from A.*
E =	0° 01′ (mark)	
F =	19 00	92 feet
H =	31 20	
C =	36 53	198 "
D =	128 42	
B =	313 20	35 "

Angle at *D* between *A* and *C* = 28° 45′
Azimuth of line *C D* = 336 18
Distance *C D* = 448.5 feet.

This latitude was determined in 1883 by observations on sixteen pairs of stars, with an average of five observations on each pair. The result is inserted here in order that the list of Hawaiian latitudes may be complete. As no special report was made on the single latitude determined on Maui in 1883, it has never yet been published. The result is

$$\varphi = 20^{\circ}\ 52'\ 22''{\cdot}8$$

The following are the results from the separate pairs:

No. of pair.	Latitude.	Number of observations.
	° ′ ″	
1	20 52 22·69	4
2	24·13	4
3	22·82	5
4	23·31	5
5	24·72	5
6	23·34	5
7	23·57	5
8	22·39	6
9	21·11	5
10	21·09	7
11	22·84	4
12	22·25	4
13	22·40	1
14	22·43	6
15	22·33	7
16	22·73	7

Abstract of magnetic results at Lahaina, Maui.

DIP.

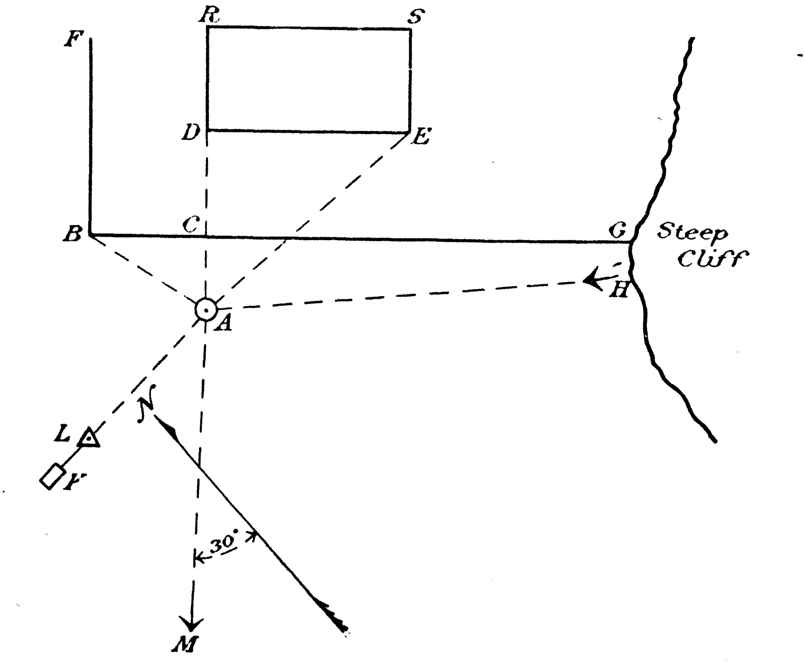
Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
Aug. 23	39 43	38 24	39 04	39 24	39 22	39 23
24	48	49	18	32	36	34
25	50	51	20	28	30	29

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
Aug. 23	-----	9 08·1	39 13·5	0·2990	124·9
24	-----	09·9	26·0	0·2980	125·4
25	28·42	08·8	24·5	0·2996	124·8

WAIMEA "A," AT KAUAI.

Returning to Honolulu on the 27th of August, preparations were made for the occupation of two stations on the Island of Kauai. The steamer left on the 30th, and I arrived at Waimea on the following day. The instruments were not landed until September 1. On the 2d observations were begun. The first station was made near the old Transit of Venus station, occupied by the English party in 1874, and reoccupied by myself in 1887 while determining astronomical latitudes for the Hawaiian Government. The following sketch explains distances and bearings:



A = Magnetic station.
K = Transit of Venus pier.
L = Latitude station, 1887.
M = Mark.
F B G = Stone wall of terrace.
H = Arrow cut in rock (said to be by Captain Cook).
R S D E = Dr. Campbell's house.

BEARINGS AND DISTANCES.

Circle readings at A.	°	′	Distances from A. Feet.
M =	0	00	....
K =	42	23	78·2
B =	140	40	35·5
D =	178	40	103·5
E =	211	25	131·0
H =	250	14	105·3
C =	...	..	30·5
K L =	...	..	11·8
B C =	...	..	16·4

The mark is the southern spire of church, about one-fourth mile southwest of magnetic station. Magnetic bearing of mark is south 30° west.

Abstract of magnetic results at Waimea, "A," Kauai.

DIP.

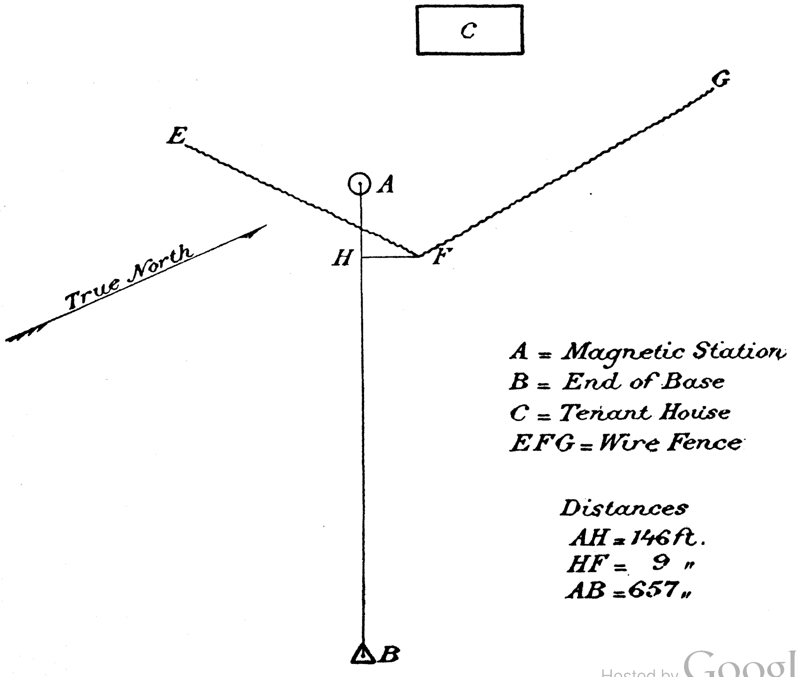
Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
Sept. 2	40 48	39 35	40 12	40 13	40 25	40 19
3	56	48	22	28	29	28

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.	*d.*	° ′	° ′	*Dyne.*	
Sept. 2	28·58	10 03·8	40 15·5	0·2886	125·2
3	-----	03·2	25·0	79	124·9

WAIMEA "B."

As it was feared that local attraction might have influenced the work at the preceding station, a second station was made at Thornycroft. This station was designated as Waimea "B," and is situated nearer the sea, on a level piece of land, with no rocks in the immediate neighborhood. It is on what is known as the Rowell property and is about one-eighth of a mile west of the house. The station is 1 015 feet north and 2 828 feet west of the Transit of Venus pier. This is taken from a large scale map made by Mr. William Rowell, and is correct within a few feet. The following sketch shows the relative positions:



Abstract of magnetic results at Waimea "B," Kauai.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
Sept. 5	40 45	39 54	40 20	40 24	40 16	40 20
6	36	55	16	22	34	28
7	44	64	24	36	20	28

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity.	Magnetic moment.
1892.		° ′	° ′	*Dyne.*	
Sept. 5	-----	9 42·6	40 20·0	0·2934	124·0
6	-----	49·2	22·0	0·2933	124·0
7	-----	47·0	26·0	0·2926	124·0

NONOPAPA, NIIHAU.

It was originally intended to close the season's work with the stations on Kauai, but as it was necessary to wait several days for the return steamer, the time was utilized by going to Niihau and getting a few observations on this island. It is the most western one of the Hawaiian group, and is rarely visited. Our magnetic observations are undoubtedly the only ones ever made on the island, and it was fortunate that the occasion presented itself for even one day's work. The conditions, however, were not very favorable. During the entire stay the wind blew violently, which precluded the possibility of determining the axis of the magnet and made all the observations extremely difficult. The station occupied was 350 feet distant from the large crane at the landing. The direction from the crane to the magnetic station was south 18° east.

Abstract of magnetic results at Nonopapa, Niihau.

DIP.

Date.	Needle No. 1.			Needle No. 2.		
	N.	S.	Mean.	N.	S.	Mean.
1892.	° ′	° ′	° ′	° ′	° ′	° ′
Sept. 9	41 01	40 08	40 34	40 35	40 51	40 43

DECLINATION, DIP, AND INTENSITY.

Date.	Scale reading of axis.	Declination (east).	Mean dip.	Horizontal intensity	Magnetic moment.
1892.		° ′	° ′	*Dyne.*	
Sept. 9	-----	10 01·4	40 38·5	0·2928	125·4

MOUNT HAMILTON, LICK OBSERVATORY, CALIFORNIA.

Leaving Honolulu at noon on September 14, we arrived at San Francisco at 1 p. m on the 21st. Passing the instruments through the custom-house and repairing the air chamber of the pendulum apparatus consumed several days, and on the 26th I left for the Lick Observatory in order to connect this station with the work done outside of the United States. Moreover, this station had been occupied several times for the determination of the force of gravity, both with the long and short pendulums, and it was desirable to check this work as well as to swing the pendulums used in the Hawaiian Islands under exceptionally favorable conditions as regards temperature and clock corrections. Observations were made on September 28, 29, and 30. The work was much facilitated by the kindness of the director, Professor Holden, a separate time correction being made by Mr. Campbell for our use.

Pendulum observations, Mount Hamilton, California.

[Observer: E. D. Preston.]

Pendulum.	Position.	Swing.	Date.	No. of coincidence intervals.	Time of ten coincidence intervals.	Semi-arc.		Temperature.	Manometer.	Barometer.	Pressure at 0° C.
						Initial.	Final.				
			1892.		*Seconds.*	*mm.*	*mm.*	° *C.*	*mm.*	*mm.*	*mm.*
B_1	D	*1	Sept. 28	12	2843·3	[5·2]	3·8	16·15	119	653·1	502·9
	D	2	28	26	2836·3	5·4	2·7	16·15	109	653·9	513·1
	D	3	28	24	2838·5	5·4	2·7	16·20	123	654·3	500·2
	R	4	28	26	2831·2	5·2	2·6	16·40	124	654·0	498·6
	R	5	28	28	2836·1	4·5	2·1	16·60	127	653·5	494·9
	R	6	28	6	2823·3	4·9	4·4	16·75	139	653·0	482·8
	D	7	28	22	2823·6	5·0	2·7	16·65	108	652·0	511·7
B_2	D	8	29	26	3185·2	4·1	1·8	14·62	134	653·6	491·9
	D	9	29	16	3169·4	5·1	3·0	14·67	129	654·0	497·0
	R	10	29	22	3181·6	5·0	2·7	14·72	132	653·8	493·8
	R	11	29	24	3179·6	5·0	2·6	14·77	137	653·0	488·2
	D	12	29	16	3167·2	5·0	3·0	14·77	130	652·5	494·4
	D	13	29	18	3175·0	5·0	3·0	14·47	133	652·5	492·0
B_3	D	14	30	18	3509·4	4·6	2·4	12·56	130	656·0	501·9
	D	15	30	20	3500·2	5·1	2·5	12·66	136	656·6	496·5
	R	16	30	20	3479·0	5·0	2·5	12·81	129	657·0	503·3
	R	17	30	18	3476·4	5·0	2·6	12·86	130	657·4	502·6
	D	18	30	28	3493·4	5·0	1·8	13·06	128	657·6	504·4
	D	19	30	20	3492·5	5·0	2·7	12·86	132	657·8	501·1

* Swing No. 1 rejected by observer.

Reduction of pendulum observations, Mount Hamilton, California.

[Periods reduced to temperature, 15° C.; pressure, 500mm at 0° C.; arc infinitely small; sidereal time.]

Period uncorrected.	Corrections (in seventh decimal place).				Period corrected.
	Arc.	Temperature.	Pressure.	Rate.	
Seconds.					*Seconds.*
0·500 8808	—71	— 48	— 2	+247	
8829	—56	— 48	—10	+247	0·500 8962
8823	—56	— 50	0	+247	964
8846	—52	— 58	+ 1	+247	984
8830	—37	— 66	+ 4	+247	978
8870	—76	— 73	+14	+247	982
8869	—51	— 68	— 9	+247	988
					976
0·500 7861	—29	+ 16	+ 6	+246	0·500 8100
7900	—57	+ 14	+ 2	+246	105
7870	—51	+ 12	+ 5	+246	082
7875	—49	+ 10	+ 9	+246	091
7906	—56	+ 10	+ 4	+246	110
7886	—56	+ 22	+ 6	+246	104
					096
0·500 7134	—42	+101	— 1	+266	0·500 7458
7153	—49	+ 97	+ 3	+266	470
7196	—48	+ 91	— 3	+266	502
7202	—49	+ 89	— 2	+266	506
7167	—38	+ 81	— 3	+266	473
7168	—51	+ 89	— 1	+266	471
					486

SUMMARY.

s.

Pendulum $B_1 = 0·5008976$

$B_2 = 0·5008096$

$B_3 = 0·5007486$

BAROMETRIC DETERMINATION OF THE HEIGHTS OF WAIMEA, KALAIEHA, AND WAIAU.

Meteorological observations were made during the month of July as a check on the heights determined trigonometrically. A barometer was read at Hilo, near the sea level, on the windward side of the island, simultaneously with similar observations at the three stations mentioned above. In addition to this, Prof. A. B. Lyons, of Oahu College, made readings at Waimea, from July 18 to July 27, which furnish independent values for the elevations sought. The observations were made at 9 a. m., 3 p. m., and 9 p. m. At Waimea the station occupied by myself was not identical with that of Professor Lyons, so there is no check on the result for this place; but by combining the Waimea observations with the continuous ones at Hilo, and with those made on the mountain during its occupancy, two very concordant independent values are obtained for Kalaieha and Waiau. Barometer Green No. 3380 was carried to the summit, and No. 3353, also by Green, was used by Professor Lyons. An intercomparison of all the instruments used showed an agreement within one hundredth of an inch in the readings when under the same conditions. The station occupied by myself at Waimea was Mr. W. L. Vredenburg's house. Professor Lyons observed at the "Lyons Mansion," which is presumably about 50 feet higher. At Kalaieha the readings were made at the northwestern cottage, about 100 feet east of the pendulum station, and approximately on the same level.

The barometer was hung in the tent at Waiau and was 3 feet higher than the surface of the lake. The Hilo observations were made some distance from the sea, and the elevation of the station is given as 100 feet, although I believe this is only an estimated value. The reductions were made by means of the Smithsonian Meteorological Tables (edition of 1893) and gave the following results:

Differences of height.

Differences of height between—	Dates of observation.	Number of readings.	Probable error of mean.	Difference in feet.
			Feet.	
Waimea (V) and Hilo	July 7 to 11	11	3	2632
Waimea (L) and Hilo	18 to 25	13	5	2672
Kalaieha and Hilo	13 to 18	18	18	6700
Waiau and Hilo	21 to 25	14	23	1 3233
Kalaieha and Waimea (L)	18 and 27	4	13	4033
Waiau and Waimea (L)	21 to 25	12	27	1 0557

From the above table we derive the elevations above Hilo as follows:

Station.	Observer, A. B. Lyons.	Observer, E. D. Preston.	Mean.
	Feet.	*Feet.*	*Feet.*
Kalaieha	6705	6700	6702
Waiau	13229	13233	13231

The triangulation made by Professor Alexander (based on the elevation of Mauna Kea primary trigonometrical station) gave the following results:

	Feet.
Mauna Kea 1^{ry} ◬ (above mean tide from previous triangulation)	13760·0
" " 2^{ry} ◬ (by leveling from above)	13804·6
Summit ◬	13810·0
Peak A = Poliahu	13646·5
" B	13468·6
Waiau astronomical station	13041·4
" Lake	13040
" crater ◬ (on outer bank of crater)	13179·4
Lilinoe	12996·5
Kalaieha latitude station	6713·6
Keonehehee	11513

The following tables give a summary of the results for the entire season's work:

Abstract of magnetic declination observations.

Station.	Date.	Scale reading of magnetic axis.	Magnetic declination.
	1891–'92.	*d.*	° ′
Waikiki, Oahu	Aug. 11	28·72	10 05·3
	12	28·80	04·9
	13	-----	05·3
	Mean	28·76	10 05·2
Kahuku, Oahu	Nov. 25	-----	10 16·4*
	26	29·34	13·0
	27	-----	14·7
	Mean	29·34	10 14·7
Honolulu	June 2	-----	10 14·7
	3	29·12	17·4
	4	29·00	16·7
	Mean	29·06	10 16·3
Kawaihae, Hawaii	July 1	29·18	9 18.7
	2	28·88	20·5
	3	-----	22·5
	Mean	29·03	9 20·6
Waimea, Hawaii (west base)	July 8	-----	8 50·0
Waimea, Hawaii (Lyons 1872)	9	-----	9 03·0
	11	-----	04·2
	Mean	-----	9 03·6
Kalaieha, Hawaii	July 14	29·06	9 53·1
	15	-----	52·1
	Mean	29·06	9 52·6
	1892.	*d.*	° ′
Waiau (summit of Mauna Kea)	July 21	30·02	10 21·0
	22	29·24	-------
	24	-----	24·4
	Mean	29·63	10 22·7
Hilo, Hawaii	July 30	-----	8 26·1*
	31	29·00	25·3
	Aug. 1	28·76	18·9
	2	-----	19·4
	Mean	28·88	8 22·4
Napoopoo, Hawaii (Captain Cook's station, 1779)	Aug. 18	28·30	9 09·2
	19	-----	10·9
	20	28·38	05·7
	21	-----	06·6
	Mean	28·34	9 08·1
Lahaina, Hawaii (De Freycinet's station 1819)	Aug. 23	-----	9 08·1*
	24	-----	09·9
	25	28·42	08·8*
	Mean	28·42	9 08·9
Waimea A, Kauai	Sept. 2	28·58	10 03·8
	3	-----	03·2
	Mean	28·58	10 03·5
Waimea B, Kauai	Sept. 5	-----	9 42·6
	6	-----	49·2
	7	-----	47·0
	Mean	-----	9 46·3
Nonopapa, Niihau	Sept. 9	-----	10 01·4

* Only a. m. or p. m. observations.

Abstract of results of magnetic dip observations.

Station.	Date.	Dip by needle No. 1.				Dip by needle No. 2.			
		N.	S.	N.-S.	Mean.	N.	S.	N.-S.	Mean.
	1891–'92.	° ′	° ′	′	° ′	° ′	° ′	′	° ′
Waikiki, Oahu	Aug. 11	40 08	39 29	+39	39 48	39 51	40 02	−11	39 56
	12	14	28	+46	51	40 10	01	+9	40 06
	13	20	28	+52	54	39 50	06	−16	39 58
Kahuku, Oahu	Nov. 25	42 01	41 01	+60	41 31	41 34	41 20	+14	41 27
	26	41 34	05	+29	20	26	28	−2	27
	27	41	07	+34	24	12	38	−26	25
Honolulu	June 2	41 02	40 10	+52	40 36	40 42	40 54	−12	40 48
	3	40 55	13	+42	34	34	46	−12	40
	4	41 10	22	+48	46	46	52	−6	49
Kawaihae, Hawaii	July 1	38 32	37 46	+46	38 09	38 04	38 15	−11	38 10
	2	42	48	+54	15	05	14	−9	10
	3	37	41	+56	09	13	16	−3	14
Waimea (west base), Hawaii	8	39 32	38 15	+77	38 54	38 30	38 25	+5	38 28
Waimea (Lyons' 72), Hawaii	9	38 38	04	+34	21	20	29	—9	24
Waimea (Lyons '72), Hawaii	11	55	34	+21	44	18	28	−10	23
Kalaieha, Hawaii	14	39 12	38 23	+49	38 48	38 50	38 50	0	38 50
	15	09	34	+35	52	39	43	−4	41
	16	14	19	+55	46	53	46	+7	50
Waiau (summit of Mauna Kea)	21	39 00	38 09	+51	38 34	38 42	38 14	+28	38 28
	22	38 57	13	+44	35	24	38	−14	31
	23	54	17	+37	36	41	42	−1	42
Hilo, Hawaii	30	39 43	39 03	+40	39 23	39 14	39 23	−9	39 18
	31	39	04	+35	22	20	32	—12	26
	Aug. 1	50	12	+38	31	25	15	+10	20
Napoopoo, Hawaii (Captain Cook's station, 1779)	18	37 56	37 22	+34	37 39	37 44	37 34	+10	37 39
	19	46	36 57	+49	22	22	46	−24	34
	20	38 08	37 10	+58	39	54	30	+24	42
Lahaina, Maui (De Freycinet's station, 1819)	23	39 43	38 24	+79	39 04	39 24	39 22	+2	39 23
	24	48	49	+59	18	32	36	−4	34
	25	50	51	+59	20	28	30	−2	29
Waimea A, Kauai	Sept. 2	40 48	39 35	+73	40 12	40 13	40 25	−12	40 19
	3	56	48	+68	22	28	29	−1	28
Waimea B, Kauai	5	40 45	39 54	+51	40 20	40 24	40 16	+8	40 20
	6	36	55	+41	16	22	34	−12	28
	7	44	40 04	+40	24	36	20	+16	28
Nonopapa, Niihau	9	41 01	40 08	+53	40 34	40 35	40 51	−16	40 43

Summary of magnetic dip.

Station.	Date.	Needles 1–2.	Dip.
	1891–'92.		° ′
Waikiki, Oahu	Aug. 11	— 8	39 52·0
	12	—15	58·5
	13	— 4	56·0
		Mean	39 55·5
Kahuku, Oahu	Nov. 25	+ 4	41 29·0
	26	— 7	23·5
	27	— 1	24·5
		Mean	41 25·7
Honolulu	June 2	—12	40 42·0
	3	— 6	37·0
	4	— 3	47·5
		Mean	40 42·2
Kawaihae, Hawaii	July 1	— 1	38 09.5
	2	+ 5	12·5
	3	— 5	11·5
		Mean	38 11·2
Waimea (west base)	8	+26	38 41·0
Waimea (Lyons, '72)	9	— 3	38 22·5
Waimea (Lyons, '72)	11	+21	33·5
		Mean	38 28·0
Kalaieha, Hawaii	14	— 2	38 49·0
	15	+11	46·5
	16	— 4	48·0
		Mean	38 47·8
	1892.		° ′
Waiau (summit of Mauna Kea)	July 21	+ 6	38 31·0
	22	+ 4	33·0
	23	— 6	39·0
		Mean	38 34·3
Hilo, Hawaii	30	+ 5	39 20·5
	31	— 4	24·0
	Aug. 1	+11	25·5
		Mean	39 23·3
Napoopoo, Hawaii (Captain Cook's station, 1779)	18	0	37 39.0
	19	—12	28·0
	20	—18	40·5
		Mean	37 35·8
Lahaina, Maui (De Freycinet's station, 1819)	23	—19	39 13·5
	24	—16	26·0
	25	— 9	24·5
		Mean	39 21·3
Waimea A, Kauai	Sept. 2	— 7	40 15·5
	3	— 6	25·0
		Mean	40 20·2
Waimea B, Kauai	5	0	40 20·0
	6	—12	22·0
	7	— 4	26·0
		Mean	40 22·7
Nonopapa, Niihau	9	— 9	40 38·5

Abstract of magnetic horizontal intensity observations.

Station.	Date.	Horizontal intensity = H (C. G. S. units).	Magnetic moment = m of intensity magnet (C. G. S. units).
	1891–'92.		
Waikiki, Oahu	Aug. 11	·2979	129·8
	12	71	9·6
	13	92	9·4
	Mean	·2981	129·6
Kahuku, Oahu	Nov. 25	·2932	129·3
	26	31	8·6
	27	48	8·6
	27	40	8·3
	Mean	·2938	128·7
Honolulu	June 2	·2954	127·9
	3	47	7·9
	4	51	7·9
	Mean	·2951	127·9
Kawaihae, Hawaii	July 1	·3001	129·4
	2	25	8·2
	3	10	7·8
	Mean	·3012	128·5
Waimea (west base)	July 8	·2966	128·0
(Lyons, '72) Hawaii	9	·2978	129·3
(Lyons, '72)	11	86	8·4
	Mean	·2982	128·8
Kalaieha, Hawaii	July 14	·2949	128·5
	15	58	8·1
	Mean	·2954	128·3
	1892.		
Waiau (summit of Mauna Kea)	July 22	·2950	123·5
	23	50	3·1
	23	50	4·1
	Mean	·2950	123·6
Hilo, Hawaii	July 30	·3064	127·0
	31	64	7·5
	Aug. 1	57	6·8
	Mean	·3062	127·1
Napoopoo, Hawaii (Captain Cook's station, 1779)	Aug. 18	·3035	124·0
	19	27	4·7
	20	11	5·3
	Mean	·3024	124·7
Lahaina, Maui (De Freycinet's station, 1819)	Aug. 23	·2990	124·9
	24	80	5·4
	25	96	4·8
	Mean	·2989	125·0
Waimea A, Kauai	Sept. 2	·2886	125·2
	3	79	4·9
	Mean	·2882	125·0
Waimea B, Kauai	Sept. 5	·2934	124·0
	6	33	4·0
	7	26	4·0
	Mean	·2931	124·0
Nonopapa, Niihau	Sept. 9	·2928	125·4

Recapitulation of results of magnetic observations.

Station.	Latitude (north).	Longitude (west of Greenwich).	Date, 1891–'92.	Declination (east).	Dip N. end below horizon.	Horizontal intensity.	Total intensity.
	° ′	° ′		° ′	° ′	*Dyne.*	*Dyne.*
Waikiki, Oahu	21 16·4	157 49·7	Aug. 11–13	10 05·2	39 55·5	0·2981	0·3887
Kahuku, Oahu	21 42·6	157 51·7	Nov. 25–27	10 14·7	41 25·7	0·2938	0·3910
Honolulu	21 18·0	157 51·5	June 2–4.	10 16·3	40 42·2	0·2951	0·3892
Kawaihae, Hawaii	20 02·4	155 47·6	July 1–3	9 20·6	38 11·2	0·3012	0·3832
Waimea (west base)	20 02·1	155 37·9	8	8 50·0	38 41·0	0·2966	0·3799
Waimea (Lyons, '72), Hawaii	20 02·0	155 37·0	9–11	9 03·6	38 28·0	0·2982	0·3809
Kalaieha, Hawaii	19 42·6	155 25·9	14–16	9 52·6	38 47·8	0·2954	0·3790
Waiau (summit of Mauna Kea)	19 49·2	155 26·8	21–25	10 22·7	38 34·3	0·2950	0·3761
Hilo, Hawaii	19 44·0	155 04·0	30–Aug. 2	8 22·4	39 23·3	0·3062	0·3962
Napoopoo, Hawaii	19 29·0	155 59·0	Aug. 18–21	9 08·1	37 35·8	0·3024	0·3819
Lahaina, Maui	20 52·0	156 40·9	23–25	9 08·9	39 20·8	0·2989	0·3865
Waimea A, Kauai	21 57·0	159 42·0	Sept. 2–3	10 03·5	40 20·2	0·2882	0·3753
Waimea B, Kauai	21 57·2	159 42·4	5–7	9 46·3	40 22·7.	0·2931	0·3848
Nonopapa, Niihau	21 55·0	160 13·0	9	10 01·4	40 38·5	0·2928	0·3859

The geographical positions are given only approximately. That of Nonopapa is uncertain.

The localities, geographical positions, and elevations of the gravity stations in order of their latitude are as follows:

Station.	Locality.	Latitude.	Longitude.	Elevation.	Elevation.
		φ (+) ° ′ ″	λ (+) ° ′ ″	*Metres.*	*Feet.*
Washington	Smithsonian Institution	38 53 20	77 01 35	10	34
Washington	C. and G. Survey Office	38 53 13	77 00 31	14	45
Mount Hamilton	Lick Observatory	37 20 25	121 38 35	1282	4205
Honolulu	Kapuaiwa Building	21 18 03	157 51 46	6	20
Waikiki	J. F. Brown's	21 16 25	157 50 01	3	10
Kawaihae	S. Parker's	20 02 25	155 49 36	2	8
Mauna Kea	Waiau	19 49 11	155 28 48	3981	13060
Kalaieha	Humuula	19 42 32	155 27 53	2030	6660

The following tables give a summary of results for each pendulum and the comparative force of gravity for each station:

Summary of results.

[Periods reduced to temperature, 15° C.; pressure, 500^{mm} at 0° C.; infinitely small arc; sidereal time.]

Station.	Pendulums.			Differences (in seventh decimal place).		
	B_1	B_2	B_3	B_1-B_2	B_2-B_3	B_1-B_3
	Seconds.	*Seconds.*	*Seconds.*			
Washington*	0·500 7828	0·500 6962	0·500 6325	+866	+637	+1503
Waikiki ('91)†	1 0871	1 0015	0 9377	+856	+638	+1494
Waikiki ('92)‡	1 0823	0 9998	0 9330	+825	+668	+1493
Honolulu	1 0797	0 9920	0 9320	+877	+600	+1477
Kawaihae	1 1157	1 0287	0 9622	+870	+665	+1535
Kalaieha	1 1946	1 1067	1 0451	+879	+616	+1495
Waiau	1 3050	1 2264	1 1457	+786	+807	+1593
Mount Hamilton	0 8976	0 8096	0 7486	+880	+610	+1490
Washington ‖	0 7794	0 6950	0 6313	+844	+637	+1481

* Smithsonian Institution, 1891.

† June 26, 27, and 28, 1891.

‡ June 3, 4, and 5, 1892.

‖ Coast and Geodetic Survey Office, 1892.

Station.	Mean period.	Relative periods.	Relative force of gravity.	Absolute force of gravity.
	Seconds.			*Dynes.*
Washington*	0·500 7026	1·000 000	1·000 000	980·100
Waikiki ('91)	0·501 0088	1·000 612	0·998 776	978·902
Waikiki ('92)	0·501 0050	1·000 604	0·998 792	978·917
Honolulu	0·501 0012	1·000 596	0·998 808	978·933
Kawaihae	0·501 0355	1·000 665	0·998 670	978·798
Kalaieha	0·501 1155	1·000 825	0·998 350	978·485
Waiau	0·501 2257	1·001 045	0·997 909	978·055
Mount Hamilton	0·500 8186	1·000 232	0·999 536	979·646

* Corrected for wear.

The pendulum observations made on the Island of Hawaii enable us to calculate the mean density of Mauna Kea from an assumed value for the earth's mean density; or, accepting a density of the mountain derived from a study of the rocks, we may reverse the problem and obtain a value of the mean density of the earth. An attempt will now be made to utilize the preceding results in both of these ways.

THE DENSITY OF MAUNA KEA AND THE MEAN DENSITY OF THE EARTH.

The formula usually employed in the treatment of the change of the force of gravity with elevation is:

$$\frac{dg}{g} = -2\frac{h}{r}\left(1 - \frac{3}{4}\frac{\delta}{\triangle}\right) \tag{1}$$

where g = the force of gravity at the sea level,
h = the elevation,
r = the radius of the earth,
δ = the density of the mountain or table-land, and
$\triangle$ = the mean density of the earth.

This formula is derived by combining the earth attraction, varying inversely as the square of the distance, with the attraction of the matter lying between the sea level and the upper station. Certain suppositions are made in regard to the form of this exterior matter and it has been generally considered a sufficient approximation to regard all the matter as equivalent to that contained in a plain of infinite extent and of a thickness equal to the elevation (h). Whether this supposition is admissible depends, of course, on the relation between vertical and horizontal dimensions of the intervening mass. If we suppose this to be of a conical form, the above term depending on the attraction of the plain must receive the correction

$$+\frac{3}{4}\frac{\delta}{\triangle}\frac{h}{\sqrt{h^2+a^2}}$$

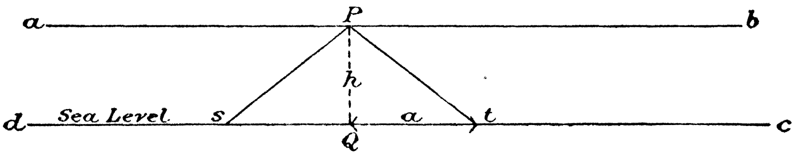
where (a) is the radius of the base.

This expression reduces to zero for an infinite value of (a) in which we have the previous case of an infinite plain. For $a = o$ the entire effect of the intervening matter disappears, as it should do in the formula. The expression for the differential of gravity at the summit of a conical mountain would therefore be:

$$dg = -\frac{2h}{r}g\left(1-\frac{3}{4}\frac{\delta}{\triangle}+\frac{3}{4}\frac{\delta}{\triangle}\frac{h}{\sqrt{h^2+a^2}}\right) \qquad (2)$$

$$= -\frac{2h}{r}g\left(1-\frac{3}{4}\frac{\delta}{\triangle}+\frac{3}{4}\frac{\delta}{\triangle}\cos\beta\right)$$

where (β) is the semivertical angle of the mountain. When (a) is very large, compared with (h), the correction for a paraboloid is $\frac{2}{3}$ and that for a sphere is $\frac{1}{2}$ that given above.* Since from the nature of the case (h) is always smaller than (a), the quantity $\frac{h}{\sqrt{h^2+a^2}}$ is never equal to unity, and the total effect of the last two terms must be essentially positive, and we have a greater value for gravity in the case of the cylinder than for the paraboloid, and a greater one for the paraboloid than for the cone. In the figure, gravity at (Q) would be diminished by passing to (P) (if no intervening matter existed) by



$$\frac{2h}{r}g = \text{correction for distance.}$$

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* Helmert, p. 172, II Theil.

If we interpose the infinite plain $(a\ b\ c\ d)$, gravity at (P) will be increased by

$$\frac{2h}{r}\,g\,\frac{3}{4}\,\frac{\delta}{\triangle} = \text{correction for plain.}$$

Since (δ) is always less than $(\triangle)$, the combined effect of these two terms will be essentially negative. The difference between the effects of the plain and the cone is seen in the last term, and the total influence exerted by matter equal in volume and position to that generated by the revolution of the trapezoid $(a\ P\ s\ d)$ around $(P\ Q)$ would be:

$$-\frac{2h}{r}\,g\,\frac{3}{4}\,\frac{\delta}{\triangle}\,\frac{h}{\sqrt{h^2+a^2}}$$

Since (a) is always very much greater than (h), the expression $\frac{h}{\sqrt{h^2+a^2}}$ is a small fraction, and the combined effect of the last two terms will be of the same sign as the first one of them; that is, their effect will be essentially positive. This is as it should be, and shows that the effect of this matter is to increase gravity at (P), whereas the effect of the first two terms would necessarily be to diminish gravity at the same point, except in the extraordinary case where the infinite plain should be one-third as heavy again as the average earth matter. A uniform density of 7·56 in an infinite plain immediately under the station would exactly counterbalance the diminution of gravity on account of distance. The negative sign attributed to the last term must not be interpreted as meaning that the actual effect of this matter is to diminish the value of gravity at (P). It rather means that, the general effect of the plain being to increase gravity at (P), the influence of $(a\ P\ s\ d)$ comes in here as expressing the difference between the effects of the plain and cone, and that the plain effect must be diminished by $\frac{3}{4}\,\frac{\delta}{\triangle}\,\frac{h}{\sqrt{h^2+a^2}}$ in order to get the cone effect. In fact, the parenthetical part of the actual plain effect being $+\frac{3}{4}\,\frac{\delta}{\triangle}$, and that of the volume $(a\ P\ s\ d)$ being $+\frac{3}{4}\,\frac{\delta}{\triangle}\,\frac{h}{\sqrt{h^2+a^2}}$, their difference, or $+\frac{3}{4}\,\frac{\delta}{\triangle}-\frac{3}{4}\,\frac{\delta}{\triangle}\,\frac{h}{\sqrt{h^2+a^2}}$, gives the actual effect for the cone as expressed in (2). For a mountain 2·5 miles high and having a radius of base equal to 30 miles $\frac{h}{\sqrt{h^2+a^2}}=\frac{1}{12}$ (nearly); so that it makes an essential difference whether we treat the mountain matter as a cone or as a plain. In this case the effect is changed by its one-twelfth part.

The formula $\frac{dg}{g}=-\frac{2h}{r}\left(1-\frac{3}{4}\,\frac{\delta}{\triangle}\right)$ has long been known as Young's Rule, although it first appeared in 1749, in Bouguer's work, "La Figure de la Terre." He makes the assumption that $\triangle = 2\,\delta$, from which the total diminution of gravity on account of distance and mass would be $\frac{5\,h}{4\,r}$. This correction has continually been applied in the treatment of mountains and table-lands by most modern observers. There has been some question whether this formula is the proper one to use, or whether, indeed, any correction at all should be made for continental attraction. It has been assumed that the whole cone of matter ($P\,s\,t$) might be brought down by compression to the line ($d\,c$) without materially altering the shape of the sea level. That is to say, that the vertical attraction at the point (P) before compression is approximately equal to that after compression. In other words, the intervening matter has no effect. This assumption has evidently been made in view of the earlier measurements of the force of gravity, which seemed to show a very small density for mountains. Two notable cases of this are, first, the Andes,* which appear to be not much heavier than ice, and the Island of Ascension, where the observed force of gravity at the sea level was actually less than that at the summit of Green Mountain,† indicating that the downward attraction of all the matter above the sea level was insignificant. These remarkable results have not always been confirmed by later observers, and recent work calls for a different interpretation of the effect of this matter. The condensation theory proposed by Professor Helmert, in his "Die Mathematischen und physikalischen Theorieen der höheren Geodäsie," makes it possible to treat pendulum observations in a way more consistent with the results of modern observations, and by so doing to derive a much more trustworthy value for the earth's ellipticity. Just how particular forms modify the density deduced for the mass lying between the sea level and the upper station is shown by the following table, which has been calculated for Kalaieha, at an elevation of 6 660 feet. The mean density of the earth is assumed as 5·67. The diminution of gravity in passing from Kawaihae (elevation 8 feet) to Kalaieha is 0·000 320 g (g being the value at the sea level).

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* La Figure de la Terre, par M. Bouguer, Paris, 1749, p. 362.

† Memoirs Royal Astronomical Society, Vol. VII, p. 60.

Figure.	Radius of base in miles.				
	10	15	20	25	30
	Density.				
Cone	4·30	4·10	4·00	3·96	3·92
Spherical segment	4·10	3·98	3·92	3·88	3·86
Cylinder	4·01	3·92	3·87	3·85	3·84
Infinite plain	3·75	3·75	3·75	3·75	3·75
	Differences for varying radius.				
Cone	0·20	0·10	0·04	0·04	
Spherical segment	0·12	0·06	0·04	0·02	
Cylinder	0·09	0·05	0·02	0·01	
Infinite plain	0·00	0·00	0·00	0·00	
	Differences from cone, for varying figure.				
Cone					
Spherical segment	0·20	0·12	0·08	0·08	0·06
Cylinder	0·09	0·06	0·05	0·03	0·02
Infinite plain	0·26	0·17	0·12	0·10	0·09

It is seen that beyond 30 miles the effect of an increase in the radius is comparatively insignificant, and that any possible change in the form of the matter after this limit is reached can not essentially modify the resulting density. The cone and the infinite plain being the extreme cases between which all other forms fall, it is worth while to compare these two in their effect on the force of gravity for the particular case under consideration. The elevation of the pendulum station at Waiau, near the summit of Mauna Kea, is 13 060 feet. The mountain is generally gradual in its ascent, and if we assume 30 miles as the radius of the base, we have $\frac{h}{a} = \frac{2·473}{30} = 0·0824 = \frac{1}{12}$.

Without stopping to inquire for the present whether Young's Rule gives a density for the mountain which is absolutely correct, for the sake of comparing Mauna Kea with other mountains a rigorous formula is perhaps not necessary. If we consider the matter lying between Waiau and the sea level as an infinite plain, as has been done in other cases, we arrive at the equation:

$$\delta = 0·536 \, \triangle$$

Taking the matter as a cone of height 2·47 miles and radius of base 30 miles, we get:

$$\delta = 0·584 \, \triangle$$

Assuming $\triangle = 5{\cdot}58$ (Harkness), we have

$$\text{for infinite plain } \delta = 2{\cdot}99$$
$$\text{for cone } \delta = 3{\cdot}26$$

Either of these values is much greater than has usually been found for other mountains, and the latter one is greater than any of the rocks found on the surface. An extensive collection of these rocks was made at different elevations, beginning at Kawaihae, on the leeward side, passing to the summit, and finally ending at Hilo, on the windward side. In all, 26 specimens were obtained. They have been carefully studied by Prof. George P. Merrill, curator of lithology at the Smithsonian Institution, who has kindly furnished the following description. The points from which they were obtained are indicated in illustration No. 31. Only 18 determinations of specific gravity were made, as this number of specimens seemed to include all the distinct types in the collection.

DESCRIPTION OF SPECIMENS.

As was the case with samples submitted by you in 1888,* and as was to be expected from papers by Dana and others† on the rocks of these islands, the samples are all basaltic lavas, differing only in degrees of crystallization, compactness, and the amount of decomposition they have undergone since their extrusion. The essential constituents of all these rocks are basic plagioclase feldspars, augites, olivines, and grains of magnetic iron, together with sporadic microscopic apatites, titanic iron, iron pyrites, and the various incipient forms of crystallization to which the convenient name of trichites may be applied. A residual glass, due to imperfect crystallization, is to be observed in greater or less abundance in nearly all cases. The microscopic characteristics of these rocks and their constituent minerals have been so well described by the above-mentioned writer that little remains to be done here but to call attention to such of their peculiarities as have a direct bearing upon the subject in hand. All stages of crystallization are to be found in the samples submitted, from those consisting almost wholly of glass (specimens D and 13), through forms carrying sharply angular or beautifully dendritic crystallizations of feldspar, augite, and olivine in a glassy base (specimen 14), to those almost wholly crystalline, exhibiting only here and there small interstitial areas of more or less devitrified glass (specimens 1, 2, 18, 23, etc.). A like variation is found in other physical properties, samples from various sources showing all gradations from highly vesicular (pumiceous) forms (specimens No. 7, 11, 13, 28, 31, 33), so light in some cases as to almost float on water, to compact glassy or crystalline varieties showing in the mass a specific gravity as high as 3·08 (specimen 2). The following notes on a few characteristic specimens will serve to show the general character of the rocks. The specific gravities given were made upon powdered material in picnometer flasks:

No. 1. A dark blue-gray rock, weathering brownish, only slightly vesicular, and showing no crystalline secretions sufficiently developed to be visible to the unaided eye. In the thin section it shows an abundance of lath-shaped plagioclases, thickly crowded together; numerous imperfectly outlined black and opaque areas, assumed to be altered augites, and an occasional yellowish-red, badly altered olivine. The ground mass is full of black opaque matter and brownish decomposition products. Specific gravity, 2·82.

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* See App. 14th Rept. U. S. Coast and Geodetic Survey for 1888, p. 529.

† See Characteristics of Volcanoes, by J. D. Dana, pp. 318–354.

No. 2. A compact dark-gray rock, with occasional small vesicles and showing phenocrysts of feldspar and occasionally augite of such size as to be visible to the naked eye. In the thin section abundant basaltic augites in irregular granular forms, interspersed with lath-shaped plagioclases, form the chief characteristics. There is the usual sprinkling of granules of iron ore, and an occasional rather small, rounded bleb of olivine. The augites and plagioclases occur in crystals of two generations. The amount of interstitial glass is proportionally small. Specific gravity, 3·08.

No. 5. A dark-gray vesicular rock, weathering brownish, and containing a comparatively large amount of iron pyrite. In the section a dense base of iron ores and small augites and plagioclases, with an abundant sprinkling of augite, olivine, and plagioclase phenocrysts. Specific gravity, 2·9.

No. 7. A finely vesicular, almost pumiceous, nearly black rock, without macroscopic constituents. In the section a dense and very opaque, partially devitrified, glassy base, carrying scattering phenocrysts of plagioclase, olivine, and augite.

No. 9. A finely vesicular, nearly black rock, with only an occasional grain of pyrite recognizable by the unaided eye. Under the microscope like 7, but with only feldspar phenocrysts. Specific gravity, 2·79.

No. 10. A compact, finely vesicular, nearly black rock, without macroscopic constituents. Under the microscope a dense, almost opaque ground mass, crowded full of granules of iron ore and lath-shaped plagioclases. Neither augites nor olivines seen in the single section examined. Specific gravity, 2·79.

No. 12. A dark-gray, nearly black, finely vesicular rock, without macroscopic constituents. Under the microscope shows only small feldspar microlites in a ground mass consisting of dark, smoky, brown glass and innumerable black opaque granules of iron ore. Between crossed nicols are seen occasional brilliantly polarizing particles, evidently olivine and augite, but too small and imperfect for absolute determination.

No. 14. In macroscopic characters like the last, but a trifle more vesicular, and with more vitreous luster; weathers brown. Under the microscope a yellow-brown glass, thickly studded with clear, colorless, sharply outlined plagioclases, olivines, and iron oxides. Specific gravity, 2·73.

No. 16. A compact, dark blue-gray rock, without macroscopic constituents, and showing in the sections under a power of 180 diameters a very dense ground mass in the form of a microgranular aggregate of minute grains of magnetic iron and nearly colorless silicates, bearing rarely greatly elongated plagioclases. The iron ore is so prominent a constituent that pieces of 0·03 gram weight were taken up by an ordinary horseshoe magnet. A rough analysis yielded—

SiO_2	40·02
Al_2O_3 and Fe_2O_3	32·80
CaO	10·20
MgO	5·19
K_2O	0·96
Na_2O (by difference)	5·19
	100·36

Specific gravity in bulk, 2·99; in powder, 3·02.

No. 17. Dark gray, nearly black, coarsely vesicular, with a few macroscopic olivines. In the section a black, smoky glass, full of iron ores and bearing abundant plagioclases in all stages of development and more rarely olivines. Specific gravity, 2·73.

No. 18. Compact, dark gray, with only an occasional small cleavage face of a feldspar sufficiently developed for determination by the unaided eye. Under the microscope a normal basalt, almost holocrystalline. Specific gravity, 2·83.

No. 19. A brownish-red, vesicular, somewhat vitreous rock, showing under the microscope a red and very opaque glassy base with numerous plagioclases.

No. 20. A brownish vesicular rock, showing under the microscope characters very similar to the last.

No. 23. A compact black rock, without macroscopic constituents. In the section a brown-black glass, injected with iron oxides and bearing numerous plagioclases and small colorless olivines. Augites quite inconspicuous. Specific gravity, 2·8.

No. 24. A close-grained dark-gray rock, showing to the naked eye only minute elongated white specks suggestive of feldspars. Under the microscope like 23.

D. A nearly black, highly vesicular rock, with frequent inclosures of pyrite. Under the microscope a yellow-brown glass with occasional large and small olivines and more numerous feldspars. Specific gravity, 2·88.

In connection with the above the following remarks may be of interest. It is a commonly accepted principle among petrologists that, the composition of the magma being the same, the physical properties of any eruptive rock are largely controlled by the conditions of cooling and crystallization, rapid cooling being conducive to the production of glassy or microcrystalline forms, while a more complete and, as a rule, coarser crystallization is developed when the cooling is more gradual. As, moreover, the conditions which govern the rate of cooling of a molten magma are mainly those of pressure from superincumbent matter—material being the same—it becomes at once apparent that those portions of any magma which are deeply buried will be the more highly crystalline. The vesicularity and consequent specific gravity (in bulk) of a lava is to a certain extent controlled by similar conditions, since this vesicularity is due to the expansion of moisture in the magma; hence the amount of moisture being the same, the superficial portions will be the more highly vesicular.

Further, it has been shown, the magma being the same, the glassy varieties of any rock are less dense than those which are crystalline. The variations are usually slight, but, as given in the published descriptions, are found to be from 0·1 to 0·3 greater in the holocrystalline than in the glassy forms.* At depths greater than have yet been rendered accessible it is possible to conceive of a still further condensation, due to a possible existence of the iron in a metallic state. Our knowledge of the physical conditions of rock masses under conditions of heat and pressure such as must exist at great depths is as yet too incomplete to afford data for anything more than speculation.† From what has been said above regarding the effects of pressure upon the physical conditions of a rock it will appear that the deeper-lying portions may be relied upon to show a greater specific gravity—the magma remaining the same—than do the superficial portions. It is obvious, therefore, that determinations on specific gravity on the samples submitted can be regarded merely as suggestive. Such determinations as I have made were, with one or two exceptions, as will be noticed, done by means of a picnometer flask, the material being first broken into small bits and weighed after the exhaustion of the air by means of a pump. The results may be regarded as in all cases a trifle under the true specific gravity of the material, since there is little probability that all the air included in the pores and vesicles was wholly removed. Below are the results obtained in the method described:

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* Thus, an average of 23 determinations of specific gravity of crystalline and semi-crystalline basalt, as given in Teall's British Petrography, shows a mean of 2·86, with extremes of 2·75–3·10, while 9 determinations on basalt glass gave a mean of 2·71 with extremes of 2·69–2·76. (British Petrography, by J. J. Harris Teall, London, 1888.)

† The presence of metallic iron in the basalt of Ovifak serves to illustrate the possibility of occurrence of this sort, although unfortunately we are not able to say definitely that this may not be a superficial phenomenon due to a reduction of the preexisting ores by carbon rather than original metallic iron from the earth's interior.

Specimen	No. 1.	Specific	gravity	2·82
“	No. 2.	“	“	3·08
“	No. 4.	“	“	2·90
“	No. 5.	“	“	2·90
“	No. 9.	“	“	2·79
“	No. 10.	“	“	2·76
“	No. 11.	“	“	2·84
“	No. 13.	“	“	2·27 (in powder)
“	No. 13.	“	“	2·12 (in bulk)
“	No. 14.	“	“	2·73
“	No. 16.	“	“	3·02 (in powder)
“	No. 16.	“	“	2·99 (in bulk)
“	No. 17.	“	“	2·73
“	No. 18.	“	“	2·83
“	No. 23.	“	“	2·80
“	D.	“	“	2·88
“	No. 13.	“	“	2·00 (other part of piece)
“	No. 33.	“	“	1·70

The mean of the preceding values is 2·7. This, according to Professor Merrill, may be slightly under the true value. A specimen from the Island of Hawaii not included in the above collection gave a value of 3·2. In Prof. E. S. Dana's "Contributions to the Petrography of the Sandwich Islands," in the American Journal of Science, June, 1889, the results of a number of determinations of specific gravity are given from the same island. Seven specimens of basalt gave values varying from 2·82 to 3·00 (page 442). Another group of seven determinations furnished examples of even heavier lava, varying from 3·00 to 3·20 (page 447). If we take the mean of the above values we get a specific gravity of 2·90 for the specimens on the Island of Hawaii. Mauna Kea has the form of truncated cone, so that its effect on the force of gravity at its summit would be intermediate between that of a cone and an infinite plain. As the difference between the ratios of $\frac{\delta}{\triangle}$ for the two forms is only about one-twelfth of the value of either, a direct mean between them will in all probability be a close approach to the actual effect of the mountain. The attraction of an infinite plain on a point above it is entirely independent of the distance of the point from the plain, and we have for the plain effect the expression

$$2\pi\delta h \text{ or } 15{\cdot}54\,\delta$$

The attractions of the earth at the upper station (Waiau) and the lower station (Kawaihae) are, respectively,

$$16566{\cdot}8\,\triangle \text{ and } 16587{\cdot}6\,\triangle$$

the linear unit being 1 mile throughout.

The forces of gravity at the two places are, when corrected for difference of latitude,

$$\begin{aligned} G \text{ at Waiau} &= 978{\cdot}067 \text{ dynes} \\ G \text{ at Kawaihae} &= 978{\cdot}798 \quad \text{“} \end{aligned}$$

The foregoing values lead to the equation

$$-0{\cdot}0007470 = -\frac{20{\cdot}8}{16587{\cdot}6} + \frac{15{\cdot}54\ \delta}{16587{\cdot}6\ \triangle}$$

$$\text{from which } \frac{\delta}{\triangle} = 0{\cdot}541$$

If we consider the mountain as a cone with an altitude of 2·473 miles and radius of base (a) of 30 miles, the attraction becomes

$$2\,\pi\,\delta\,h\left[1 - \frac{h}{\sqrt{h^2 + a^2}}\right] = 14{\cdot}26\ \delta$$

and the resulting value of $\frac{\delta}{\triangle}$ is 0·589.

We may therefore assume that the density of the earth is 1·77 times the density of the mountain, or that the

$$\text{mean density of earth} = 1{\cdot}77 \times 2{\cdot}90 = 5{\cdot}13$$

SUMMARY.

List of stations occupied in the Hawaiian Islands, with results obtained.

1883– 1887—1891–2.

No.	Station.	Island.	Date of occupation.	Height (feet).	Latitude.	Longitude.
					° ′ ″	*h. m. s.*
1	Nonopapa	Niihau	Sept., 1892			
2	Waimea "B"	Kauai	" "			
3	Waimea "A"	"	Feb. and Mar., 1887		21 57 00·8	
4	" "A"	"	Sept., 1892			
5	Hanalei	"	Mar., 1887		22 12 56·5	
6	Koloa	"	" "		21 52 13·2	
7	Puuloa	Oahu	Jan., "		21 19 15·6	
8	Kahuku	"	Feb., "		21 43 06·1	
9	"	"	Nov., 1892			
10	Honolulu	"	June, 1883	12		
11	"	"	Apr., 1887		21 18 02·5	
12	"	"	June, "	10		
13	"	"	" 1892	20		
14	Waikiki	"	May, 1891*			
15	"	"	June and Dec., 1891	10	21 16 24·3	
16	"	"	Jan. and June, 1892	10	21 16 24·7	10 31 18·6
17	Lahaina	Maui	June, 1883	10	20 52 22·8	
18	"	"	Aug., 1892			
19	Haiku	"	June, 1887	385	20 56 02·6	
20	Pakaoao	"	July, "	9846	20 42 51·0	
21	Kaupo	"	July and Aug., 1887		20 36 40·8	
22	Hana	"	July, "		20 45 38·9	
23	Kailua	Hawaii	June, "		19 38 20·9	
24	Napoopoo	"	Aug., 1892			
25	Kawaihae	"	July, "	8	20 02 05·9	
26	Kohala	"	Apr., 1887		20 15 29·3	
27	Ka Lae	"	May, "		18 53 51·7	
28	Waimea	"	July, 1892	2772		
29	" (west base)	"	" "			
30	Waiau	"	" "	13060	19 48 52·0	
31	Kalaieha	"	" "	6660	19 42 02·6	
32	Hilo	"	Apr. and May, 1887		19 43 11·2	
33	"	"	July and Aug., 1892			

*Transit of Mercury.

SUMMARY.

List of stations occupied in the Hawaiian Islands, with results obtained.

No.	Magnetic elements.			Force of gravity.	
	Declination (east).	Dip.	Hor. inten.	Relative.	Absolute.
	° ′	° ′	*Dyne.*		*Dynes.*
1	10 01·4	40 38·5	0·2928		
2	9 46·3	40 22·7	0·2931		
3	10 03·5	40 20·2	0·2882		
4					
5					
6					
7					
8					
9	10 14·7	41 25·7	0·2938		
10				0·998 836	978·959
11					
12				0·998 852	978·975
13	10 16·3	40 42·2	0·2951	0·998 808	978·932
14*					
15	10 05·2	39 55·5	0·2981	0·998 776	978·900
16				0·998 792	978·916
17				0·998 724	978·850
18	9 08·9	39 20·8	0·2989		
19				0·998 790	978·914
20				0·998 142	978·279
21					
22					
23					
24	9 08·1	37 35·8	0·3024		
25	9 20·6	38 11·2	0·3012	0·998 672	978·799
26					
27					
28	9 03·6	38 28·0	0·2982		
29	8 50·0	38 41·0	0·2996		
30	10 22·7	38 34·3	0·2950	0·997 913	978·055
31	9 52·6	38 47·8	0·2954	0·998 352	978·485
32					
33	8 22·4	39 23·3	0·3062		

* Time of transit = $4^h\ 43^m\ 57^s$, second and third contacts.

The relative forces of gravity refer to the value at the Smithsonian Institution in Washington. In the absolute column this is assumed to be 980·100 dynes, and the given values are the best ones attainable from the three expeditions.

SUPPLEMENTARY NOTE TO THE FOREGOING REPORT.

Since the foregoing report was written, Professor Alexander has made a comparison of the astronomical and geodetic latitudes on the three principal islands of the group. In addition to this, since the observed latitudes at Kawaihae, Hilo, and Waiau (Mauna Kea) are consistent with one another, the latter has been adopted as a standard, and a comparison has been made between the observed latitudes and the Mauna Kea standard. This brings out some interesting deflections of the plumb line.

There appears to be a disturbance of more than a minute in the direction of gravity at the south point of Hawaii (Ka Lae). At Kohala the plumb line is deflected half a minute toward the south, and at Kalaieha nearly as much toward the north, the disturbance being in both cases toward the mountain. The enormous deflection at Ka Lae (67″) is also to the northward. This is evidently caused by the great mass of Mauna Loa,* which adds its effect to that of Mauna Kea, and, moreover, is comparatively near to the astronomical station.

On Maui the same phenomenon appears. At Haiku there is a deflection toward the south, and at Kaupo there is one to the north, and, as before, the astronomical latitude determined on the top of Haleakala (10 000 feet elevation), at Pakaoao, appears to be a normal one for that island. Judging by analogy, there seems to be no reasonable doubt that Oahu would have shown the same thing had a station been made on the summit between Kahuka and Puuloa.

The mean deflection for each of the islands (leaving out Ka Lae, on the Island of Hawaii) is:

	″
Hawaii	27
Maui	29
Oahu	26

When we come to compare the mean latitudes for each island with one another, we find that Maui is too small, whether judged by the Hawaii or the Oahu standard. The amount is nearly the same in either case, so that the most probable assumption is that there is a preponderance of matter deflecting the plumb line to the northward at all the Maui stations. This supposition has been made by Professor Alexander, and seems to be the most rational interpretation of the results. The following table has been furnished by him, and is inserted here with his permission:

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* Both Mauna Kea and Mauna Loa are nearly 14 000 feet high.

Hawaiian latitudes compared.

[See illustration No. 23.]

Station.	Astronomical.			Geodetic.			Diff.	Mauna Kea standard.			Diff.
Oahu.	°	′	″	°	′	″	″	°	′	″	″
Kahuku	21	43	06·1	21	42	16·1	+50·0	21	42	43·2	+22·9
Puuloa	21	19	15·6	21	19	11·8	+ 3·8	21	19	38·9	−23·3
Honolulu	21	18	02·5	21	18	02·3	+ 0·2	21	18	29·0	−27·1
Waikiki	21	16	24·5	21	16	26·8	− 2·3	21	16	53·9	−29·4
Maui.											
Lahaina	20	52	22·8	20	52	53·2	30·4	20	52	34·5	11·7
Haiku	20	56	02·6	20	56	04·0	− 1·4	20	55	45·3	+17·3
Pakaoao	20	42	51·0	20	43	21·6	30·6	20	43	02·9	11·9
Kaupo	20	36	40·8	20	37	41·0	−60·2	20	37	22·3	41·5
Hana	20	45	38·9	20	45	47·5	− 8·6	20	45	28·8	+10·1
Hawaii.											
Kohala	20	15	29·3	20	15	17·7	+11·6	20	14	59·0	+30·3
Kawaihae	20	02	05·9	20	02	25·1	−19·2	20	02	06·4	0·5
Mauna Kea	19	48	52·0	19	49	10·7	−18·7	19	48	52·0	+ 0·0
Kalaieha	19	42	02·6	19	42	33·5	−30·9	19	42	14·8	−12·2
Hilo	19	43	11·2	19	43	30·4	−19·2	19	43	11·7	0·5
Kailua	19	38	20·9	19	39	03·8	−42·9	19	38	45·1	24·2
Ka Lae	18	53	51·7	18	55	17·7	−86·0	18	54	59·0	67·3

Positions for Lahaina:	° ′ ″
By observation	20 52 22·8
“ Oahu mean latitude	32·3
“ Mauna Kea standard	34·5

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